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# Contents

**Research Papers**

1. Growth and yield response of potato (*Solanum tuberosum* L) to organic and blended fertilizers – Seid Hussen Muhie and Tesfanesh Goli 1

2. Effect of growth regulators on the formation of potato (*Solanum tuberosum* L.) micro-plants *in vitro* – R. Asakaviciute and A. Razukas 10

3. Kufri Uday: An early maturing red skin potato variety – SK Luthra, VK Gupta, Sanjay Rawal, Bandana, Vinod Kumar, Vinay Bhardwaj, SK Chakrabarti and MS Kadian 17

4. Adaptive models for determining cropland suitability and total harvest prediction for potato using IOT – Rindra Yusianto, Guruh Fajar Shidiq, Herwin Suprijono and Marimin 26

5. Evaluation of conventional and zero tillage for potato cultivation in rice – potato sequence – Shiv Pratap Singh, MJ Sadawarti, S Rawal, VK Dua, SK Sharma and YP Singh 38

6. Kufri Kiran: A new heat tolerant potato variety – VK Gupta, Vinay Bhardwaj, SK Luthra, Brajesh Singh, Devender Kumar, Babita Chaudhary, Sanjay Rawal, Kamlesh Malik, JS Minhas, Manoj Kumar, M Paratpara Rao and SK Chakrabarti 45

7. Characterization of andigena accessions for biotic stress resistance using linked molecular markers – Vikas Mangal, Salej Sood, Ashwani Kumar, Baljeet Singh, Bhawna Dipta, Vinay Bhardwaj, Dalamu, Vinod Kumar, Sanjeev Sharma, Ajay Kumar Thakur, A K Sharma and Brajesh Singh 55

8. Biodiversity of weeds in potato (*Solanum tuberosum*) in Pangalengan and Cikajang sub-districts of Indonesia – Umiyati U, Denny Kurniadie and Intan Ratna Dewi Anjarsari 66

9. Kufri Lohit: A new red skin potato variety – SK Luthra, VK Gupta, Babita Chaudhary, Sanjay Rawal and Mehi Lal 77

10. Irradiated potatoes identification by thermoluminescence and seed tubers growth analysis in case of low gamma dose and late irradiation – Asma Benaidja, Rabah Yefsah, Belkacem Mansouri and Faycal Kharfi 89

11. Kufri Manik: A red- skinned biofortified potato variety – Shambhu Kumar, Dalamu, Jagdev Sharma, SK Luthra, Vinay Bhardwaj and SK Chakrabarti 99

**Short Note**

12. Potato micropropagation in a medium devoid of any plant growth regulators – Tanuja Buckseth, Sumita Sharma, Jagesh K Tiwari, Ashwani K Sharma, MJ Sadawarti and Vinod Kumar 107

Potato J (2023) 50 (1): 1-9

# GROWTH AND YIELD RESPONSE OF POTATO (*SOLANUM TUBEROSUM* L*)* TO ORGANIC AND BLENDED FERTILIZERS

**Seid Hussen Muhie* and Tesfanesh Goli**

**ABSTRACT: Appropriate nutrition management of the potato crop is crucial during the entire growth period as part of a successful agronomic strategy. In places of mid and high altitude where present yields of potato (Solanum tuberosum L.) are less than 10 t ha$^{-1}$, where production is severely hampered by inadequate soil fertility, Ethiopia has a significant potential to boost potato production and productivity. A field experiment was conducted to determine the effects of integrated application of blended NPS fertilizer and compost on growth, yield parameters and yield of potato (Solanum tuberosum L.), variety 'Belete' under irrigation at Efrata Gidim District, North Showa, Ethiopia in 2022 cropping season. The treatments consisted of four Nitrogen-Phosphorus-Sulfur (NPS) blended fertilizer levels (0, 50,100 and 150 kg ha$^{-1}$) and three compost levels (0, 10 and 20 t ha$^{-1}$). The experiment was laid out as a Randomized Complete Block Design (RCBD) in a factorial arrangement and replicated three times. Data were collected and statistically analyzed using SAS version 9.2 software. The findings revealed that the highest marketable tuber number per plant (14.1), total tuber number per plant (17.6), marketable tuber yield (13.0 t ha$^{-1}$) and total tuber yield (15.48 t ha$^{-1}$) were obtained from combined application of 150 kg ha$^{-1}$ NPS blended fertilizer and 20 t ha$^{-1}$ compost. The integrated application of nutrients might have benefited the crop to access the essential elements for growth and development. The result can be temporarily recommended for potato producers around the study areas and similar agroecologies.**

**KEYWORDS:** Compost; NPS fertilizer; Marketable tuber; Steam number; Tuber yield

## INTRODUCTION

The potato (*Solanum tuberosum* L.), a member of the Solanaceae family and the genus Solanum (Reddy *et al*., 2018) is the 4$^{th}$ most significant food crop in the world after rice, wheat, and maize (Mangal *et al*., 2022) but it ranked 1$^{st}$ among the non-cereal crops (Muhie, 2022b). By giving small-holder farmers direct and immediate access to nutritious food, raising household income, and lowering their vulnerability to fluctuates in food prices, potato cropping methods serve to promote resilience, especially among small-holder farmers (Mitiku *et al*., 2019).

The potato is a crop with a significant potential for guaranteeing food security in Ethiopia because of its high nutritional content, high - yielding potential, quick growth, and broad range of plasticity (Tewodros *et al*., 2014). As one of the essential crops mentioned in the Millennium Development Goals for guaranteeing food security and the elimination of poverty, potatoes were designated as the crop of the year by the United Nations in 2008. Since the price of potatoes is more impacted by local supply and demand than by the global market, it might still help provide food security. The early maturity of potatoes and their short growing cycle are further advantages of potatoes over many other crops. In the primary cropping season of Ethiopia, over 1.04 million households produced 1,141,871.7 t of potatoes on an estimated 85, 988 hectares of land. However, the productivity of this crop in the country is rather poor when compared to the global average yield of 19 tha$^{-1}$ (13.28 t ha$^{-1}$) (CSA, 2021).

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Potatoes are extremely dependent on the nutrient status in the soil due to their short, coarse, and underdeveloped root structure. The crop generates much more dry matter in less time than most soils can typically provide, exhausting a large amount more nutrients per unit of time (King *et al*., 2020). Use of organic manure and inorganic fertilizers may have a major impact on the production of the potato crop. Organic manures and their extracts have been shown to increase soil fertility, soil structure, and plant resistance to pests and diseases (Muhie, 2022c; Raghunandan *et al*., 2019). Research on organic manure is required because of worries about soil drowsiness and nutritional imbalances created by excessive and careless application of inorganic fertilizers, even though these mineral fertilizers such as NPS can be used to replenish soil nutrients and boost agricultural yields. However, because of its limited availability, poor nutrient content, high application rates, and labor-intensive nature, using organic fertilizer alone might not completely meet crop nutritional needs (Osterholz *et al*., 2017). Producers should apply novel approaches and practices for sustainable production of high value crops thereby improve their livelihood (Muhie, 2022a). Integrated application of organic fertilizers (compost, vermicompost, manure) and inorganic fertilizers (blended) could substantially influence the yield of potato.

These integrated use of these blended fertilizers with compost have not been studied due to previous research on fertilizer determination being restricted to the two common macronutrients, N and P. Under irrigation and rain-fed circumstances, local farmers grow potatoes for both food and profit. Nevertheless, there isn't a thorough prescription for NPS fertilizers for the local irrigation systems. This continues to discourage local farmers from looking into more effective methods of growing potatoes. In light of these worries, it was aimed that experiments about integrated use of organic and blended fertilizers would shed some light on the effects of various fertilizer concentrations on productivity and related factors, such as potato growth, tuber yield, size distribution, and related yield qualities. Therefore, direct investigation of the response of potato to integrated application of blended inorganic fertilizer (NPS) and organic fertilizer (compost) was required to come up with optimum fertilizer recommendations rates so as to improve productivity of the potato crop.

## MATERIALS AND METHODS

### Description of the Study Area

The experiment was carried out in Ethiopia's Efrata Gidm district's North Shewa zone during the 2022 growing season under irrigation. The region lies 273 kilometers from Addis Ababa in the north-eastern region of Ethiopia. Geographically, the region is located at 10° 33' N latitude, 39° 35' E longitude, and 1470 meters above sea level (masl) elevation (Figure 1).

The area's agroecology includes kola (low land), woyna dega (mid land), and dega (high land). The area's minimum and highest temperatures are 12 and 30 degrees Celsius, respectively. The average annual rainfall is 1004 millimeters. The soil at the test site has a typically clay loam texture. The major horticultural crops grown in the study area are potato, onion, paper, tomato and cabbage (Efrata Gidim Woreda ARDO, personal communication).

### Experimental Materials

The potato cultivar "Belete" from the Debre-Birhan Agricultural Research Center (located at latitude 9° 67' and longitude 39° 53') was used as a test crop. It is intended for altitudes of

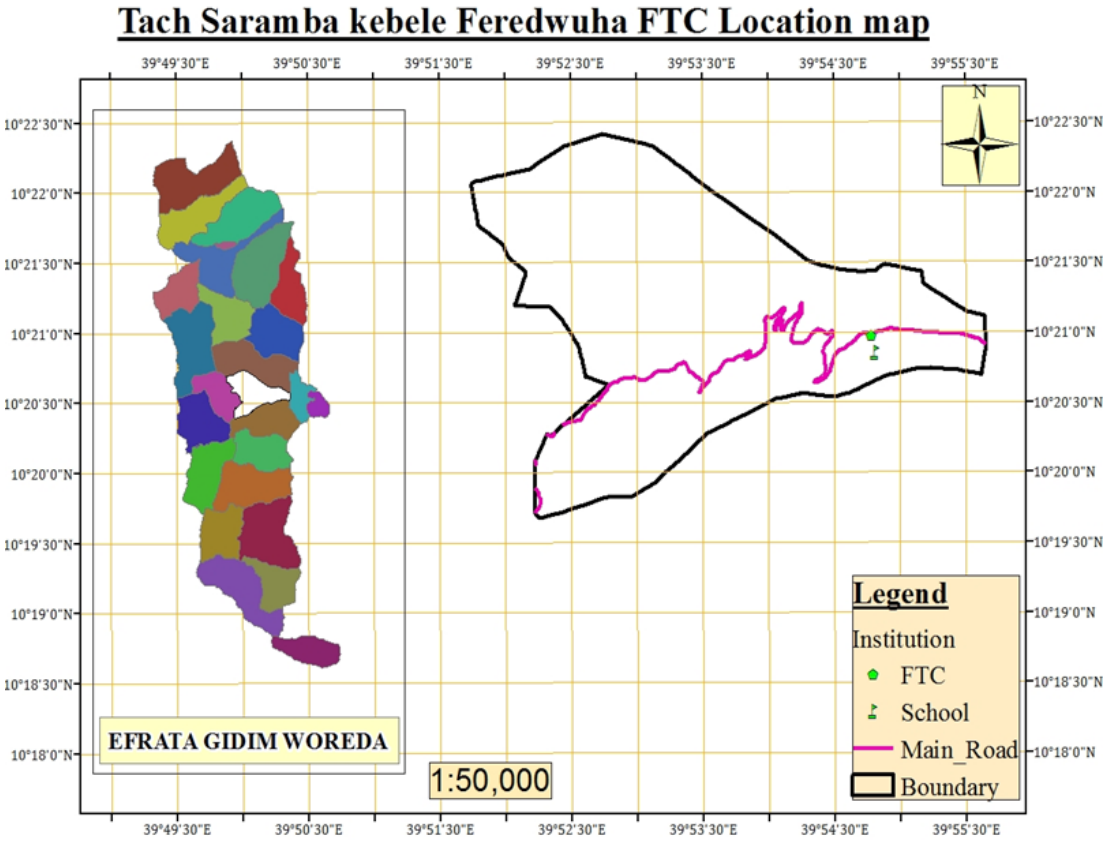



*Figure 1. Map of study area*

1600 to 2800 masl. It is the cultivar that is most regularly farmed in North Showa, Ethiopia. For planting, medium-sized, equally-sized tubers that had a healthy sprout were utilized.

## Experimental treatments, design and procedures

The treatments consisted of four level of NPS blended fertilizer application rates (0, 50, 100 and 150kg $ha^{-1}$) and three level of compost rates (0, 10 and 20t $ha^{-1}$), which were assigned randomly to each plot. The experimental design was laid out in a Randomized Complete Block Design (RCBD) in three replications with path width of 1 meter between plots and 1.5 meter between blocks. The gross size of experimental plot was 3 m x 3 m (9 $m^2$) accommodating 4 rows of potato at a spacing of 75 cm between rows and 30 cm between plants.

## Soil Properties before Planting

As shown in Table 1, the soil's physical and chemical characteristics in the experimental field. The experimental site's soil textural class was sandy clay loam. Hazelton & Murphy, (2016) rated the soil of the experimental field as having a slightly acidic pH (6.5), very low levels of organic carbon (0.50%), very low levels of organic matter (0.86%), low levels of total nitrogen (0.12%), and extremely low levels of available phosphorus (7.56 mg $kg^{-1}$). The soil's Cation Exchange Capacity (CEC) was 39.84 cmol $kg^{-1}$ (Table 1). CEC normally increases as pH, clay, and organic matter levels rise because clay and organic particles have the capacity to draw and hold cations. The Cation exchange capacity of the soil is a

**Table 1. Soil physical and chemical properties of the experimental site before planting at Efrata Gidim in 2022**

| Physical properties | | | | Chemical properties | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Particle size Distribution (%) | | | | pH | OC (%) | OM (%) | Total N (%) | Available P (Mg kg$^{-1}$) | CEC (Cmol kg$^{-1}$) |
| Sand (%) | Silt (%) | Clay (%) | Textural Class | | | | | | |
| 52 | 21 | 27 | SCL | 6.5 | 0.50 | 0.86 | 0.12 | 7.56 | 39.84 |

Where: - OC- organic carbon, OM- organic matter, TN- total Nitrogen, Available P. - available phosphorus, CEC- Cation exchange capacity and SCL- Sandy Clay Loam.

crucial factor to take into account in order to identify the type of clay mineral present in the soil and its capacity to prevent nutrients from leaching. As a result, it is reasonable to deduce from the soil analysis results that nitrogen and phosphorus may be factors that limit the output of potatoes grown in the area.

## Method of Data Collection and Analysis

Plants in the plot area were used to collect all the growth and yield parameters such as lant height, main stem numbers, marketable tuber numbers per plant, unmarketable tuber numbers per plant, total tuber number plant, marketable tuber yield per hectare, total tuber yield per hectare.

## RESULTS AND DISCUSSION

### Plant height

On plant height, the major impacts of the NPS mixed fertilizer and compost rates as well as their interactions were very significant ($P<0.01$). The 150 kg NPS ha$^{-1}$ + 20 t compost ha$^{-1}$ treatment combination produced the tallest plant height (111 cm). The mean plant height grew as the different rates of NPS mixed fertilizers were raised from zero to 150kg ha$^{-1}$. Similar to this, raising the various compost rates from zero to 20 t ha$^{-1}$ also increased plant height (Table 2).

The current finding is consistent with Ababiya, (2018), who showed that plots fertilized with cattle manure at a rate of 20 t ha$^{-1}$ and NPK 150 kg ha$^{-1}$ had higher values of plant height than plots fertilized with just cattle manure or NPK mineral fertilizer. The results are also consistent with those of Zewide *et al*., (2018), who reported that the integrated application of organic and inorganic fertilizers may be attributed to the provision of adequate micro and macronutrients. This improvement in micronutrient availability is likely what helped to increase metabolic activity during the early growth phase, which in turn likely helped to promote overall growth. The majority of the necessary nutrients were provided by the organic manure and inorganic fertilizer during the growth stage, which led to a rise in growth variables, including plant height (Itelima *et al*., 2018). Lombardo *et al*., (2020) found that plants grown with N and P fertilizer and CM were noticeably taller than those in the control plots, which is consistent with our findings.

**Table 2. Interaction effect of NPS blended fertilizer and compost on plant height (cm) at Efrata Gidim District in 2022**

| | NPS rate (kg ha$^{-1}$) | | | | |
|---|---|---|---|---|---|
| Compost (t ha$^{-1}$) | 0 | 50 | 100 | 150 | Mean |
| 0 | 87.87$^{h}$ | 93.7$^{ef}$ | 93.23$^{fg}$ | 98.27$^{cd}$ | 93.27 |
| 10 | 89.27$^{gh}$ | 98.2$^{cd}$ | 100.57$^{c}$ | 105.0$^{b}$ | 98.26 |
| 20 | 95.8$^{def}$ | 97.43$^{cde}$ | 107.83$^{ab}$ | 111.0$^{a}$ | 103.02 |
| Mean | 90.98 | 96.44 | 100.54 | 104.76 | |
| LSD (0.05) | | | 4.14 | | |
| CV (%) | | | 2.49 | | |

LSD (0.05) = Least Significant Difference at 5% level; CV (%) = Coefficient of variation. Means in the table followed by the same letter are not significantly different at 5% level of significance.

## Marketable tuber numbers per plant

The highest marketable tuber numbers per plant (14.1) was recorded from treatment combination of 150 kg NPS $ha^{-1}$ + 20 t compost $ha^{-1}$ followed by (13.17) from treatment combination of 150 kg NPS $ha^{-1}$ + 10 t compost $ha^{-1}$ (Table 3). The marketable tuber numbers per plant increased with increasing compost application rate because the compost applied to soil might have resulted in an increase in carbon mineralization in the soil due to available carbon for microbial respiration and provision of nitrogen. However, the lowest marketable tubers numbers per plant (7.13) was obtained from treatment combination of zero NPS and zero compost of the control plots (Table 3).

The synergistic effect of mineral NP and cattle manure could be responsible for the high marketable tuber yields attained by the combined application of mineral and organic fertilizers (Zewide *et al*., 2021). The presence of an acceptable amount of nitrogen may have improved vegetative growth and increased photoassimilation, both of which contributed to the highest observed marketable number of tubers per hill from the highest combined application of NPS mixed fertilizer and cattle dung (Getacher, 2021). Similarly, Wilkinson *et al*., (2020) demonstrated that the number of marketable tubers increased significantly as the sulfur rate increased. This is likely because sulfur plays a role in the synthesis of sulfur-containing amino acids, proteins, energy conversion, and enzyme activation, all of which improve carbohydrate metabolism and the photosynthetic activity of plants with increased chlorophyll synthesis. This was crucial for the processes of photosynthesis and net assimilation, and it appears that no re-absorption from the tubers occurred, resulting in an increase in tuber size and weight so the tuber could be marketed.

**Table 3. Interaction effects of NPS blended fertilizer and compost on marketable tuber numbers per plant of potato at Efrata Gidim District in 2022.**

| | NPS rate (kg $ha^{-1}$) | | | | |
|---|---|---|---|---|---|
| Compost (t $ha^{-1}$) | 0 | 50 | 100 | 150 | Mean |
| 0 | $7.13^{e}$ | $10.57^{c}$ | $10.63^{c}$ | $10.67^{c}$ | 9.75 |
| 10 | $8.7^{d}$ | $10.97^{bc}$ | $11.8^{b}$ | $13.17^{a}$ | 11.16 |
| 20 | $10.5^{c}$ | $11.27^{bc}$ | $11.93^{b}$ | $14.1^{a}$ | 11.95 |
| Mean | 8.78 | 10.94 | 11.45 | 12.65 | |
| LSD (0.05) | | | 0.98 | | |
| CV (%) | | | 5.26 | | |

LSD (0.05) = Least Significant Difference at 5% level; CV (%) = Coefficient of variation. Means in the table followed by the same letter are not significantly different at 5% level of significance.

## Total tubers numbers per plant

The main effect of NPS fertilizer and compost rates highly significantly ($P<0.01$) influenced total tuber numbers per plant while, the interaction effect of NPS fertilizers with compost rates was significant ($P<0.05$) influenced total tuber numbers per plant. The highest total tuber numbers per plant (17.6) was recorded from treatment combination of 150 kg NPS $ha^{-1}$ + 20 t compost $ha^{-1}$ (Table 4). The total tuber numbers per plant was increased with combined application of organic and inorganic fertilizers compared to sole application of NPS blended fertilizers and compost. This might be due to its higher nutrient composition and capacity to increase availability of native soil nutrient through higher biological activity. The lowest total tuber numbers per plant (9.57) was recorded from treatment combination of zero NPS and zero compost of the control plots (Table 4).

The result of this study is in agreement with Bhujel *et al*., (2021) who reported that the increase in total tuber numbers per plant is in response to the increased application of the combined NPS fertilizers and CM might be due to the increased photosynthetic activity and translocation of synthesized

**Table 4. Interaction effects of NPS blended fertilizer and compost on total tuber numbers per plant of potato at Efrata Gidim District in 2022.**

| | NPS rate (kg ha$^{-1}$) | | | | |
|---|---|---|---|---|---|
| Compost (t ha$^{-1}$) | 0 | 50 | 100 | 150 | Mean |
| 0 | 9.57$^{g}$ | 13.57$^{e}$ | 13.87$^{e}$ | 13.97$^{de}$ | 12.75 |
| 10 | 11.23$^{f}$ | 14.4$^{cde}$ | 15.23$^{bcd}$ | 16.57$^{ab}$ | 14.36 |
| 20 | 13.53$^{e}$ | 14.7$^{cde}$ | 15.43$^{bc}$ | 17.6$^{a}$ | 15.32 |
| Mean | 11.44 | 14.22 | 14.84 | 16.05 | |
| LSD (0.05) | | | 1.35 | | |
| CV (%) | | | 5.67 | | |

LSD (0.05) = Least Significant Difference at 5% level; CV (%) = Coefficient of variation. Means in the table followed by the same letter are not significantly different at 5% level of significance.

**Table 5. Interaction effects of NPS blended fertilizer and compost on marketable tuber yield (quintal ha$^{-1}$) of potato at Efrata Gidim District in 2022**

| | NPS rate (kg ha$^{-1}$) | | | | |
|---|---|---|---|---|---|
| Compost (t ha$^{-1}$) | 0 | 50 | 100 | 150 | Mean |
| 0 | 6.23$^{f}$ | 7.69$^{de}$ | 7.8$^{de}$ | 8.87$^{d}$ | 7.58 |
| 10 | 6.73$^{ef}$ | 10.83$^{c}$ | 11.59$^{bc}$ | 12.26$^{ab}$ | 10.35 |
| 20 | 7.22$^{e}$ | 10.87$^{c}$ | 12.26$^{ab}$ | 13.0$^{a}$ | 10.84 |
| Mean | 6.64 | 9.79 | 10.55 | 11.37 | |
| LSD (0.05) | | | 1.21 | | |
| CV (%) | | | 7.47 | | |

LSD (0.05) = Least Significant Difference at 5% level; CV (%) = Coefficient of variation. Means in the table followed by the same letter are not significantly different at 5% level of significance.

product/photo assimilate to the root, which is probably helped in the initiation of more stolon in potato. Taheri *et al*., (2011) also found the highest ratio (13.07%) of number of large tubers as a result of application of 20 t compost ha$^{-1}$ of combined with 225 kg P ha$^{-1}$ and 50 kg zinc ha$^{-1}$. Other researchers also reported significant tuber numbers per plant increment in response to increasing N rates and increase in cattle manure application (Masrie *et al*., 2015).

## Marketable tuber yield

The analysis of variance showed that main effect of NPS blended fertilizer and compost rates and their interaction showed significant (P<0.01) effect on marketable tuber yield of potato. The highest marketable tuber yield (265.6 q ha$^{-1}$) was recorded from treatment combination of 150 kg NPS blended fertilizer ha$^{-1}$ + 20 t compost ha$^{-1}$ followed by 150 kg NPS blended fertilizer ha$^{-1}$ + 10 t compost ha$^{-1}$ and 100 kg NPS blended fertilizer ha$^{-1}$ + 20 t compost ha$^{-1}$ with marketable tuber yield of 12.258 and 12.257 tha$^{-1}$ respectively (Table 5). However, the lowest marketable tuber yield (6.23 tha$^{-1}$) was recorded from treatment combination of zero NPS and zero compost of control treatment (Table 5). The control plot produced the lowest values for marketable tuber yield of potato, due to the absence of adequate nutrient level needed for proper growth, development and yield.

The result of this study is in agreement with Amin, (2018) who showed that combining mineral fertilizers with cattle manure prolonged the release and added more macro and micro nutrient thereby promoting better crop growth and marketable tuber yield of potato. The possible reasons for the maximum marketable tuber yield ha$^{-1}$ observed with the higher combined application of NPS blended fertilizer and CM could be due to a function of total biomass production, the percentage of biomass that is partitioned to the tubers, the moisture content of the tubers and the proportion of tubers that are acceptable to the market, in terms of size and lack of defects; and great opportunities exist to increase potato yield and quality by improving nutrient management (Mekashaw *et al*., 2020).

## Total tuber yield

The main effects of NPS blended fertilizer and compost rates had highly significant (P<0.01) effect on total tuber yield, while, the interaction effect of NPS blended fertilizers

and compost had significant ($P<0.05$) influence on total tuber yield of potato. The highest total tuber yield (316.33 q $ha^{-1}$) was obtained from combined application of 150 kg NPS blended fertilizer $ha^{-1}$ + 20 t compost $ha^{-1}$ followed by 150 kg NPS blended fertilizer $ha^{-1}$ + 10 t compost $ha^{-1}$ and 100 kg NPS blended fertilizer $ha^{-1}$ + 20 t compost $ha^{-1}$ with total tuber yield of 14.55 and 14.48 $tha^{-1}$ respectively (Table 6). On the other hand the lowest total tuber yield (7.83 $tha^{-1}$) was obtained from the treatment combination of zero NPS and zero compost of control treatment (Table 6).

The result of this study is in agreement with Balemi, (2012) who reported that application of 20 or 30 t $ha^{-1}$ FYM + 66.6% of the recommended inorganic NP fertilizers significantly increased total tubers yield. The presence of nutrients in manure and balanced supplement of nitrogen and phosphorus through mineral fertilizers might have contributed to increased cell division, expansion of cell wall, meristematic activity, photosynthetic efficiency and regulation of water intake into the cells, resulting in the enhancement of yield parameters (Mohammadi *et al.,* 2013).

This result is consistent with that of Ababiya, (2018), who reported that the variation in the rate of application of organic manure and inorganic fertilizers could influence the yield of potato. Atanaw, (2021) also observed that tuber yield was increased by the combined use of cow dung and NPK (20: 10: 10) compared to sole application of cow dung or NPK. Maximum tuber yield (36.8 t $ha^{-1}$) was obtained by using 150 kg N $ha^{-1}$ + 20 t CM $ha^{-1}$ (Darzi et al., 2012).

**Table 6. Interaction effects of NPS blended fertilizer and compost on total tuber yield ($tha^{-1}$) of potato at Efrata Gidim District in 2022.**

| | NPS rate (kg $ha^{-1}$) | | | | |
|---|---|---|---|---|---|
| Compost (t $ha^{-1}$) | 0 | 50 | 100 | 150 | Mean |
| 0 | $7.83^{g}$ | $9.74^{ef}$ | $9.86^{ef}$ | $10.99^{e}$ | 9.60 |
| 10 | $8.74^{fg}$ | $12.98^{d}$ | $13.78^{bcd}$ | $14.55^{ab}$ | 12.51 |
| 20 | $9.05^{fg}$ | $13.1^{cd}$ | $14.48^{abc}$ | $15.48^{a}$ | 13.03 |
| Mean | 8.54 | 11.94 | 12.71 | 13.67 | |
| LSD (0.05) | | | 1.42 | | |
| CV (%) | | | 7.18 | | |

LSD (0.05) = Least Significant Difference at 5% level; CV (%) = Coefficient of variation. Means in the table followed by the same letter are not significantly different at 5% level of significance.

## CONCLUSIONS

Potato is a tuber vegetable which is considered as heavy feeder. It growth and yield response to the application nutrients is significant. In the present study the combined application of blended NPS fertilizer and compost improved growth, yield and yield components of potato. Accordingly, the highest marketable tuber number per plant (14.1), total tuber number per plant (17.6), marketable tuber yield (13.0 t ha-1) and total tuber yield (15.48 $ha^{-1}$) were obtained from combined application of 150 kg $ha^{-1}$ NPS blended fertilizer and 20 t $ha^{-1}$ compost. When the rate of NPS and compost increased, all the growth and yield parameters of potato also increased. The integrated application of nutrients might have benefited the crop to access the essential elements for growth and development. The soil of the experimental site is also low in nutrient such as N and P. Hence, the application of compost could benefit the crop through supply nutrients and modification of the soil structure. The experiment clearly indicated the benefits of integrated nutrient management (organic and inorganic fertilizers). The result can be temporarily recommended for potato producers around the area and similar agroecologies. However, to validate the findings of the current experiment, it has to be repeated across seasons and locations with different types of organic fertilizers.

## CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest.

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# EFFECT OF GROWTH REGULATORS ON THE FORMATION OF POTATO (*SOLANUM TUBEROSUM* L.) MICRO-PLANTS *IN VITRO*

**R. Asakaviciute* and A. Razukas**

**ABSTRACT: Effect of growth regulators IAR (indole-3-acetic acid) and kinetin (6-furfuryl aminopurine) on length and mass formation of micro-plants of different maturity table potatoes (*Solanum tuberosum* L.) varieties was evaluated. The varieties of different maturity group included were very early 'VB Venta', early 'Goda', medium early 'VB Meda' and very late 'VB Aista'. Microplant explants were grown in modified MS nutrient medium with different concentrations of growth regulators.. The concentration of 1.75 ml/l of auxin resulted in significant increase in length and weight of the micro-plant with highest micro plant growth (10.03± 0.96 cm) and mass (0.218 ± 0.09 g) formation in var 'VB Meda' compared to least growth in VB Venta' (6.2 ± 0.75 cm). Kinetin at concentration of 0.8 ml/l resulted in longest micro-plants formation by 'VB Meda' variety (9.03 ± 0.18 cm) and the smallest by 'VB Venta' (5.20 ± 0.15 cm) explants.**

**KEYWORDS:** growth regulators, *Solanum tuberosum* L., micro-plants, *in vitro*, genotype

## INTRODUCTION

Potatoes are able to easily adapt to various growing conditions, are distinguished by high yields and nutritional value, therefore they are very widespread and are considered the most important non-grained agricultural plant in the world. Potatoes are also one of the main raw materials for starch extraction, and the starch content of potatoes is usually between 9% and 25% (Acharjee *et al*., 2018). Because potato tubers cannot be stored for a long time, the use of potatoes in the form of starch and modified products has become an excellent alternative toa (Fernie and Willmitzer, 2001; Sonnewald and Sonnewald, 2014). According to the Food and Agriculture Organization of the United Nations (FAO), potatoes rank fourth after corn, rice, and wheat in terms of the volume of world production in tonnes (FAO, 2011). Due to the nutritional value of potatoes since ancient times, they are called the second bread. Potato tubers, depending on the variety, accumulate 15-35% of dry matter, of which starch 17-29%, protein - 1-2%, mineral salts - about 1%. When comparing vegetable proteins, potatoes are inferior only to wheat and buckwheat. Almost three times more dry matter can be obtained from a unit of area for potatoes than from grain fodder plants. In addition, potato tubers contain potassium, sodium, calcium, magnesium, phosphorus, iron. According to the total amount of mineral compounds accumulated in potatoes, they exceed many types of fruits and vegetables. 18 amino acids are found in potato proteins. Potatoes are characterized by high nutritional value and are a source of vitamins C, $A_1$ (carotene), group B, $PP_1$ and K. By eating an average of 300 g of boiled potatoes every day, we provide ourselves with the necessary carbohydrates, phosphorus, vitamin $B_2$ 10-12%, amino acids – 30-40%, vitamin C – 40-50%, vitamin $B_1$ – 20-25%, potassium – 55-60%, calcium and iron – 25-30% and carotene – 1-2%. Due to the excellent taste, nutritional and culinary

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qualities, potatoes have become a product of almost daily use. Potatoes also have healing properties (Leonel *et al*., 2017).

The meristemic method of potato seeding is currently the most promising and fastest for seed potato reproduction. Meristem culture may have been the first biotechnological method used to remove viruses from systematically infected potato clones. Over the years, this technique has been successfully combined with the method of microproduction to bring out potato seeds without diseases. The rapid reproduction of these disease-free clones using microproduction in combination with conventional propagation methods has now become an integral part of seed production in many countries (Barrell *et al*., 2013). The technique of plant tissue culture has become an alternative in recent years and has become popular as an alternative method of vegetative propagation of plants (Hajare *et al*., 2021). As a modern technology, plant tissue culture has great potential to meet the ever-growing demand of the world. Healthy, thermotherapeutically cleaned of viruses, without bacterial and fungal beginnings, potatoes are grown from the meristemic cells of the seedling growth cone. In this way, not only good quality is achieved, but conditions are created for the significantly faster reproduction of potatoes of new varieties (Roosher, 1988; Hajare *et al*., 2021).

Microdescence is a method of vegetative propagation *in culture in vitro*, designed to multiply quickly and in large quantities by plants. When propagated in this way, many plants in a small space are regenerated from a small explant. In this work, microvegetative reproduction was used. This method is aimed at cloning plants, while maintaining their genetic and physiological characteristics. The optimal composition of the medium and the growing conditions for each species may be fundamentally different, so they are determined experimentally.

Phytohormones are needed to control *in vitro* plant cells, tissues, organs, or entire plant crops according to the desired results: maintain vitality, grow, initiate organogenesis (the formation of organs, for example, the formation of a stem with leaves or roots), and so on. Without phytohormones, plant growth could not be controlled (Ohnuma *et al*., 2020; Hajare *et al*., 2021).

*The purpose of the work.* To study the effect of growth regulators on micro-plants of potatoes (*Solanum tuberosum* L.) *in vitro*.

*The work has the following tasks:* 1. To study the effect of indoleyl-3-acetic acid (IAR) on different microgrowths of potatoes; 2. Determine the most appropriate concentration of indoleyl-3-acetic acid (IAR) for micro-plants *in vitro*; 3. To study the effects of 6-furfurylaminopurin (kinetin) on different microgrowths of potatoes; 4. Determine the most appropriate concentration of 6-furfurylaminopurin (kinetin) for micro-plants *in vitro*.

## MATERIALS AND METHODS

The experiment was prepared and carried out at the Biotechnology Laboratory of the Lithuanian Center for Agrarian and Forest Sciences and at the Institute of Agriculture of Vokė brancho (Vilnius) in 2021.

*The purpose of the work.* To study the effects of growth regulators on micro-plants of potatoes (*Solanum tuberosum* L) *in vitro*.

*The object of res earch.* Microgrowths of edible potatoes (*Solanum tuberosum* L.) of different varieties (Table 1) of different maturity: very early 'VB Venta', early 'Goda', medium early 'VB Meda' and late 'VB Aista', as well as growth regulators IAR (indolyl-3-acetic acid) (Figs. 2 and 3) and kinetin (6-furfurylaminopurin).

**Table 1: Pedigree information of Lithuanian potato cultivars**

| Varieties | Registration LTU | Maturity | Parentage |
|---|---|---|---|
| 'VB Venta' | 2009 | Very early | 'Priekuliu visagrie' × 'Pirmunes' |
| 'Good' | 2004 | Early | 'Ausonia' ×'Franzi' |
| 'VB Meda' | 2019 | Medium | 'Matilda' × No.3093 |
| 'VB Aista' | 2006 | Very late | No.263 -× No.476-9 |

Murashige & Skoog (MS) medium (Murashige and Skoog, 1962; Saker *et al*., 2012) is one of the most widely used nourishing media for tissue cultures. An important feature of this medium is the high concentration of nitrates, potassium, and ammonium ions. The nourishing medium is sterile in an autoclave at 120 °C at 0.75–1.00 atm. sfor pressure, 30 min with a pH = 5.7-5.8. Microgrowths are cut and planted in a nutrient medium of a certain concentration of phytohormones (5 ml). The planted explants were kept *in vitro in a* tumor, where the photoperiod is automatically regulated - during the day for 16 hours the seedlings grow in the light (12 thousand km). Lx), 8 a.m. in the dark. The air temperature during the day is up to 24 °C, at night it is about 21 °C, and the humidity is 86-90%. Length (cm) and mass (g) of micro-plants measured during the tests.

*Test 1:* The influence of IAR on microgrowths.

2-factor (AxB) test: A – explantants of potato varieties ('VB Venta', 'Goda', 'VB Meda' and 'VB Aista'); B – 3-indolylacetic acid (IAR) concentrations of 0.0, 1.0, 1.25, 1.5, 1.75 and 2.0 ml/l(solutions prepared by dilution method). Potato explants were planted in mediums of different concentrations of January 5-7 mention year. Biometric indicators were measured 4 weeks later (Fig. 5), when microgrowths formed new 4-7 leaflets. For 4 genotypes and 6 concentrations (one option planted 50 pieces explants), during the entire test – 1200 explants.

*Test 2*: Effect of kinetins on microgrowths.

2-factor (AxB) test: A – explantants of potato varieties ('VB Venta', 'Goda', 'VB Meda' and 'VB Aista'); B – kinetin concentrations – 0.0, 0.4, 0.5, 0.6, 0.7 and 0.8 ml/l (solutions prepared by the dilution method). Potato explants were planted in mediums of different kinetin concentrations on February 9-10 mention year. Biometric indicators were measured 4 weeks later, when microgrowths formed new 4-7 leaflets. For 4 genotypes and 6 concentrations (one option planted 50 pieces explants), during the entire test – 1200 explants.

Statistics of Figure 1-4 show means and their standard deviations (x ± SD). The reliability of differences between samplings was assessed by the dispersion analysis with further evaluation of the least significant difference (LSD) using the Statistica 5 software package.

## RESULTS AND DISCUSSION

### Description of Lithuanian potato varieties

'VB Venta' (2009). The maturity of the variety is very early. Tubers are round, with medium-deep eyes. Skin and flesh color is light yellow. Cooking characteristics are perfect. There is no browning after peeling. Taste is excellent. The variety is salad type. Starch content is up to 14-16%. The variety is resistant to wart disease, field resistance to the black legand potato leaf roll virus. Storage characteristics under controlled conditions are excellent.

'Goda' (2004). The variety is early. Tubers are oval round, medium in size, with shallow eyes. Flesh and skin colour is light yellow.

Sugar content is low. No discoloration after peeling and cooking. Suitable for chips industry. Starch content is up to 16-17%. The variety is resistant to potato cyst nematode Ro1 and wart disease. Foliage is resistant and tubers fully resistant to the late blight. Storage is good.

'VB Meda' (2019). The plant is compact and medium. The flower colour is white with short flowering period. Tubers are oval, shallow eyes, yellow skin, and flesh, and rough. Potato variety has low reducing sugars. Table varieties suitable for baking. Tubers do not change colour when baking and boiling. Great taste and other culinary qualities. Starch content is up to 14-17%. Resistant to potato cyst nematodes $Ro_1$ patotype, immune to potato cancer, has good resistance to viruses. Tubers have resistant to late blight. Variety has good storage conditions. Potato variety grows all soils. Due to its high resistance to potato diseases, it is suitable for ecological farming.

'VB Aista' (2006). This is a late, food potato variety. The bush is stretched out, the stems are tall. The flowers are white, of medium size. The variety flowers abundantly and for a long time. The tubers are big, yellowish, flat round with shallow eyes. The output of commercial tubers is 90%. Starch content is high, up to 21%. The variety is good for starch industry. The potatoes are palatable. The boiled potatoes do not get dark, boil soft. The variety is resistant to wart disease, potato cyst nematode $R_{o1}$, late blight. The variety is resistant to drought, can be grown in all kinds of soil using proper cultivation techniques. The variety is resistant to mechanical injuries while harvesting; characterized by good storage quality.

The effect of all phytohormones on plants is quite polyvalent. All of them affect cell growth and division, adaptation and aging processes, substance circulation, respiration, nucleic acid and protein synthesis, etc. However, each group has its own specific effect (Ohnuma *et al.,* 2020). Potatoes, like other plants, have a whole known group of phytohormones. For example, the different hormones contained in potatoes (IAA, CK, OR, JA) stimulate some stages of tuberization, and GA inhibits them (Kolachevskaya *et al.,* 2018). Auxins play a very important role at almost all stages of the development of the plant, which require changes in the meristem. Studies *using* auxins in vitro highlight their importance for tubers (Roumeliotis *et al.,* 2012).

High concentrations of auxins can and without cytokinins cause mitosis in somatic plant cells. In general, it is necessary to determine the adequate levels of concentration of auxins and cytokinins for plant regeneration.

## The influence of auxin (IAR) on the formation of microgrowths

The study used 4 potato genotypes, as the in *vitro* productivity of explants depends on the amount of IAR in the culture medium. Tested nourishing medium with IAR concentrations of 1.0, 1.25, 1.5, 1,75 and 2,0 ml/l.

The results of the studies showed that the highest microgrowths were the 'VB Meda' varieties (10. 03 ± 0.96 cm), the lowest – 'VB Venta' (6. 2 ± 0.75 cm) (Fig. 1 a). Most of the masses of micro-plants were formed by the varieties of 'VB Meda' (0. 218 ± 0.09 g) explants (Fig. 1, b).

Summing up the results of the length and mass of micro-plants, it can be said that for the explants of the 'VB Meda' variety, the effect of IAR was the greatest. The explants of the 'VB Aista', 'Goda' and 'VB Venta' varieties also developed well.

When using a golden concentration of 1.75 ml/l, a sharp increase in the length of the

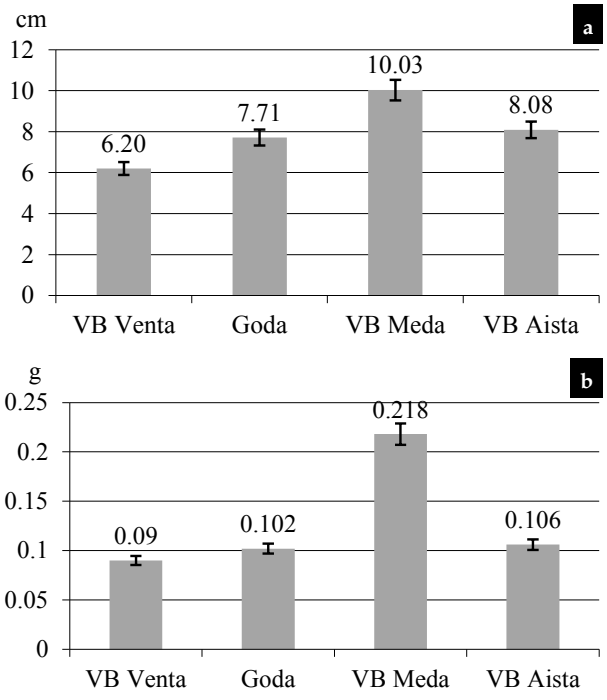



**Fig. 1.** *The influence of different potato genotypes on the length of micro-plants (a) ($LSD_{01(A)}$ = 0.521) and (b) for mass ($LSD_{01(A)}$ = 0. 037) using auxin (IAR)*

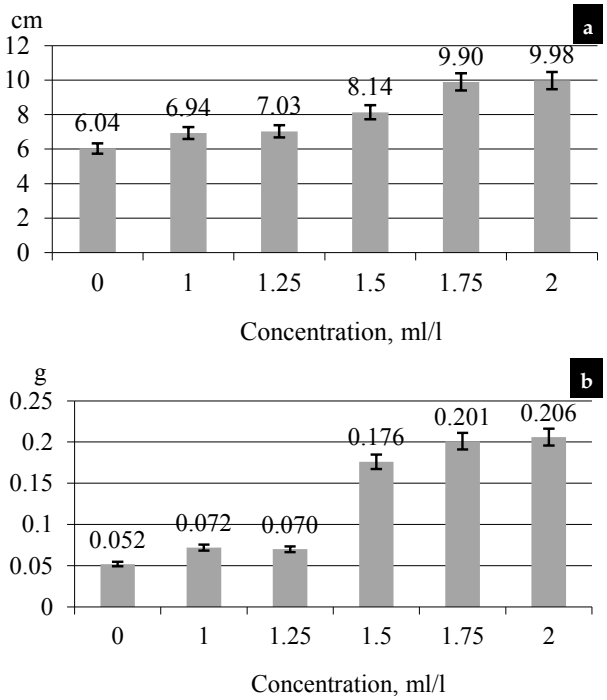



**Fig. 2.** *The effect of auxin (IAR) on the length of micro-plants (a) ($LSD_{01(B)}$ = 0. 675) and (b) for mass ($LSD_{01(B)}$ = 0.082)*

micro-plants $LSD_{01(AxB)}$ = 1.430 (Fig. 2, a) and the mass $LSD_{01(AxB)}$ = 0.047 (Fig. 2, b) is observed.

Summarizing the results of the concentrations of the IAR compound of 1.75 and 2.0 ml/l had a positive effect on most tests. The scientific literature states that for stem morphogenesis, the optimal concentration of auxins is 1.0 ml/l (Ohnuma *et al*., 2020). Our study showed that the optimal concentration for microgrowths is 1.75 ml/l. Auxin (IAR) stimulated cell swelling and growth, in part and cell division.

## The influence of kinetin on the formation of microgrowths

In the study, 4 potato genotypes were used, as the in *vitro* productivity of explants depends on the amount of kinetins in the culture medium. Tested nourishing medium with 0.4, 0.5, 0.6 in concentrations of 0.7 and 0.8 ml/l of kinetin.

The results of the test showed that the length of micro-plants in different potato genotypes is different (Fig. 3, a). The longest microgrowths were shaped by 'VB Meda' (9. 03 ± 0.18 cm) and the smallest ones are exhibitors of the 'VB Venta' variety (5.2 ± 0.15 cm).

Summarizing the results of the length and mass of micro-plants (Fig. 3, b), it can be said that the kinetin effect was greatest on the explants of the 'VB Meda' variety. The explants of the 'Goda', 'VB Aista' and 'VB Venta' varieties also developed well.

When using a concentration of kinetin 0.8 ml/l, an increase in the length of the micro-plants $LSD_{01(AxB)}$ = 1.286 (Fig. 4, a) and the mass $LSD_{01(AxB)}$ = 0.021 (Fig. 4, b) are observed. Summarizing the results of the length and mass of micro-plants, it can be said that the effect of 0.4, 0.5, 0.6, 0.7 and 0.8 ml/l of the

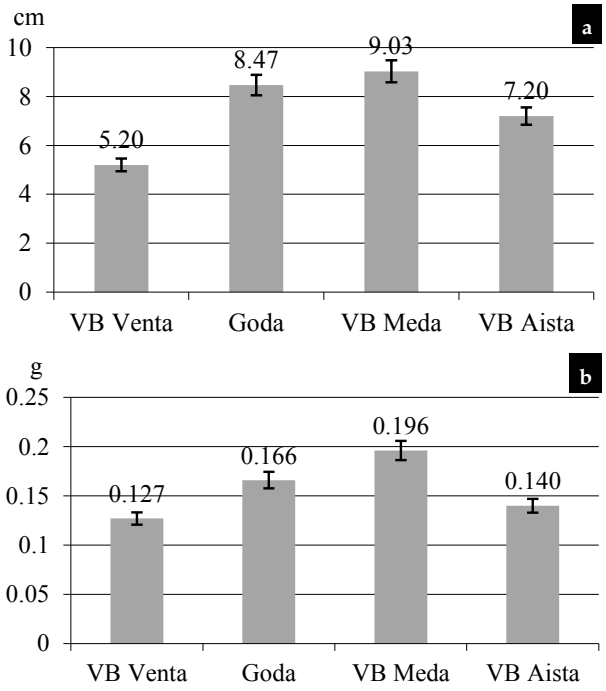



**Fig. 3.** *The influence of different potato genotypes on the length of micro-plants (a) ($LSD_{01(A)}$ = 0.341) and (b) for mass ($LSD_{01(A)}$ = 0.046) using kinetin.*

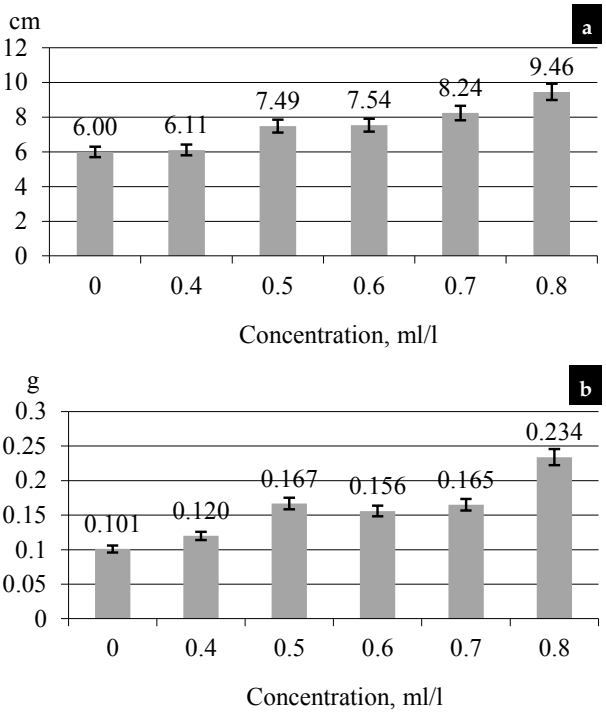



**Fig. 4.** *The effect of kinetin on the length of micro-plants (a) ($LSD_{01(B)}$ = 0.754) and (b) for mass ($LSD_{01(B)}$ = 0.031)*

kinetin compound concentrations of on most tests was positive.

It is believed that the formation and development of leaves *in vitro* had a significant positive influence on the IAR and kinetin. Perhaps the amount of endogenous phytohormones was determined by the genotype of the plant and thus influenced the dependence of organogenesis on the content of exogenous hormones. In the scientific literature it is indicated that most often the effect of one phytohormone on the metabolism of another is not direct but is a consequence of the functional effect on the activity of tissues.

## CONCLUSION

After assessing the length and mass of the potato micro-plants using five concentrations of indolyl-3acetic acid (IAR), it was observed that the IAR effect was greatest on the explants of the 'VB Meda' variety. The explants of the 'VB Aista', 'Goda' and 'VB Venta' varieties also developed well. The study of the influence of the five concentrations of indolyl-3acetic acid (IAR) on microgrowths of the 'VB Venta', 'Goda', 'VB Meda' and 'VB Aista' varieties of potatoes *in vitro* showed that the optimum concentration for the length and mass of micro-plants is 1,75 ml/l. After assessing the length and mass of the micro-plants of potatoes using five concentrations of 6-furfurylaminopurin (kinetin), it was noted that for the explantants of the 'VB Meda' variety, the kinetin effect was greatest. The explants of the 'Goda', 'VB Aista' and 'VB Venta' varieties also developed well. The study of the influence of five concentrations of 6-furfurylaminopurin (kinetin) on microgrowths of potatoes of the varieties 'VB Venta', 'Goda', 'Goda', 'VB Meda' and 'VB Aista' in *vitro* showed the maximum length of micro-plants (9.46 ± 0.27

cm) and mass (0.234 ± 0.012 g) obtained using a concentration of 0.8 ml/l.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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# KUFRI UDAY: AN EARLY MATURING RED SKIN POTATO VARIETY

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**ABSTRACT: Kufri Uday is an early maturing, main season, high yielding table potato variety suitable for cultivation in North Indian plains (Northern, Central, and Eastern plains). It is a clonal selection from the cross between CIP387521.3 × Aphrodite. Its plants are medium tall and vigorous with field resistance to late blight. It produces attractive red coloured ovoid tubers with shallow eyes, yellow flesh, and a mealy texture. The new variety possesses 18-19% tuber dry matter and very good keeping quality. It is fertilizer responsive and capable of yielding 36–38 t/ha under optimum agronomical practices.**

**KEYWORDS:** Kufri Uday, variety, table potato, early maturity, red skin, high yield, late blight, keeping quality, North-Indian plains

## INTRODUCTION

In India, though mostly white or yellow skinned potatoes are preferred by consumers, however, red skin potatoes are liked mainly in the eastern part of India. But, the preference for red skin potatoes is increasing in other areas also due to the liking of the migrant population and more awareness about red potatoes among people. Market supply chain dynamics are also influencing potato growers in different regions for raising red skin varieties. Efforts are continuing for developing better genotypes in this segment for potato growers and consumers to meet the ever-increasing demand. The concerted effort, in this direction, has led to the identification of an early maturing, high yielding, late blight resistant variety named Kufri Uday.

## BACKGROUND

CP4409 (CIP392797.22 - C92.140) was developed at International Potato Center (CIP), Lima Peru in 1992 and was brought to India in 2012 under ICAR-CIP collaborative programme on potato crop improvement. The clone CP4409 (CIP392797.22) (LTVR-Low land tropic virus resistant) is a descendant of cross CIP387521.3 × Aphrodite. In Peru, the clone is known to be resistant to late blight, and field testing in 17 areas of Peru's coastal lowlands, confirmed it to be tolerant to heat, drought, and soil salinity (https://cipotato.org/blog/unica-a-potato-for-farmers-around-the-world/). The CIP advanced clone, CIP392797.22 has been officially released in different countries as Unica (Peru, 1998), Qingshu 9 (China, 2011), Tajikistan (Tajikistan, 2014), Yusi Maap (Bhutan, 2017), Mkanano (Africa, 2018), Unica (CIP392797.22) (Nigeria, 2023). Local experts estimated that more than 150,000 hectares in China were planted with Qingshu 9 in 2015 (https://www.rtb.cgiar.org/news/improved-potato-variety-qingshu-9-success-story/). Clone CIP392797.22, a red-skinned, high yielding and moderately resistant to late blight, was released as

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'Yusi Maap', and it is a micronutrient (iron and zinc) dense variety (Bajgai *et al*. 2018). This clone is presently being evaluated for possible release in Uzbekistan and Georgia. This variety is one of the most adaptable, high yielding and climate resilient potato varieties across the globe (Luthra *et al.* 2022). The pedigree of CP4409 is described in Fig. 1. The female parent CIP387521.3 belongs to International Potato Center (CIP), Lima Peru, whereas the male parent Aphrodite is from the Netherlands. Aphrodite is a very early to early maturing variety with a slight resistance to late blight and produces white/ yellow ovoid tubers with shallow eyes and light yellow flesh colour.

In India, the advanced clone CP4409 was evaluated during the main season at Modipuram (2014-15, 2015-16, and 2016-17) following the breeding procedure of Luthra *et al*. 2022 and based on its superior performance; it was introduced in All India Co-ordinated Research Project (AICRP) - Potato and tested during 2018-19, 2019-20 and 2020-21 at 8 locations in North Indian plains comprising northern, central and eastern plains. It showed wider adaptability and higher yield than the controls. The data was analyzed following standard statistical procedures using the online statistical software OPSTAT, CCS HAU, Hisar, Haryana (Sheoran *et al*, 1998).

The advanced clone CIP392797.22 (CP4409) under AICRP trials in India was however got released in Bhutan as Yusi Maap (2017) and subsequently, it was notified in India (2019) under the Regional Seed Agreement for plains of India. However, in the Foreign Aided Project Meeting of the Horticultural Sciences Division, ICAR, New Delhi on 22nd June 2022, the name of Yusi Maap was changed to Kufri Uday as per the tradition of ICAR-CPRI.

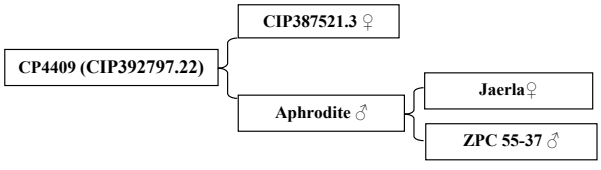



*Fig.1. Pedigree of Kufri Uday*

## VARIETAL DESCRIPTION

Morphological characteristics of the variety Kufri Uday (leaf, flower, sprout, and tuber) have been depicted in Fig. 2.

***Plant:*** Medium, canopy semi-compact, stem medium thick, predominantly green, secondary stem colour red brown throughout lightly scattered, wings poorly developed and straight.

***Foliage:*** Grey green, leaves open, leaf width medium, leaflets ovate lanceolate, leaflet coalescence absent, rachis coloured, midrib coloured at the base.

### Inflorescence

***Flowering:*** Flowering medium, inflorescence small, floral stalk medium coloured, floral




*Fig. 2. Morphological characteristics of Kufri Uday: Leaf, flowers, tuber and sprout*

stalk-pedicle articulation clearly visible and located above the middle, calyx light red brown, corolla red violet, corolla shape pentagonal, anther yellow, anther cone normally developed, stylar length longer than stamen column and stigma round uni-lobed.

### Tubers

***Size:*** Medium to large, 8-9 tubers per plant; *Shape:* Ovoid; *Skin:* Smooth and red; *Eyes:* Shallow, predominantly apical; *Eyebrows:* Normal; *Flesh:* Yellow with a mealy texture.

### Sprout

Red purple, spherical, pubescence at sprout base is weak, sprout tip closed, length of apical sprout is medium (2-5 cm).

## YIELD PERFORMANCE

**Station trials:** CP4409 (43.02 t/ha) yielded 11 and 21 % higher total tuber yield over Kufri Lalit (38.75 t/ha) and Kufri Lalima (35.65 t/ha), respectively at 90 days (**Table 1**). It produced nearly 95% marketable tuber yield as compared to Kufri Lalit (95%) and Kufri Lalima (94%). The variety with 40.91 t/ha marketable tuber yield showed benefits of 11 and 23% respectively over control varieties Kufri Lalit (36.83 t/ha) and Kufri Lalima (33.39 t/ha).

**Multi-location testing:** Replicated yield trials with controls were conducted at 8 locations during 2018-19 and 2019-20 (**Table 2**) and 2020-21 (**Table 3**) in North Indian plains comprising Northern (Jalandhar, Hissar, Modipuram), Central (Kanpur) and Eastern plains (Bhubaneshwar, Faizabad, Kalyani, Patna).

### Replicated yield trials (2018-19 & 2019-20)

**Crop duration (75 days):** Based on the pooled performance of eight locations, advanced clone CP4409 (30.01 t/ha) yielded 7 and 16 % higher total tuber yield over Kufri Lalit (27.97 t/ha) and Kufri Lalima (25.91 t/ha), respectively (**Table 2**). CP4409 produced nearly 93% marketable tuber yield as compared to Kufri Lalit (91%) and Kufri Lalima (87%).

**Crop duration (90 days):** The results pooled over eight locations, showed superior performance of advanced clone CP4409 (37.40 t/ha) by 7 and 17 % for higher total tuber yield as compared to Kufri Lalit (35.07 t/ha) and Kufri Lalima (32.03 t/ha), respectively (**Table 2**). CP4409 produced nearly 93% marketable tuber yield as compared to Kufri Lalit (93%) and Kufri Lalima (91%).

### Replicated yield trials (2020-21)

**Crop duration (75 days):** Based on the pooled performance of eight locations, advanced clone CP4409 (32.59 t/ha) yielded 16, 17 and 24% higher total tuber yield over Kufri Manik (28.12 t/ha), Kufri Lalit (27.93 t/ha) and Kufri Lalima (26.30 t/ha), respectively (**Table 3**). CP4409 produced nearly 88% marketable tuber yield as compared to Kufri

**Table 1. Mean performance of CP4409 at Modipuram during 2014-2017**

| Genotypes | Tuber yield (t/ha) at 90 days | | | | | | | | % Yield ± over controls | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014-15 | | 2015-16 | | 2016-17 | | Mean | | | |
| | MTY | TTY | MTY | TTY | MTY | TTY | MTY | TTY | MTY | TTY |
| CP4409 | 33.37 | 35.10 | 46.55 | 48.85 | 42.80 | 45.12 | 40.91 | 43.02 | - | - |
| Kufri Lalit | 30.83 | 32.79 | 41.62 | 43.73 | 38.04 | 39.73 | 36.83 | 38.75 | 11.08 | 11.02 |
| Kufri Lalima | 27.86 | 29.99 | 37.65 | 40.15 | 34.65 | 36.80 | 33.39 | 35.65 | 22.52 | 20.67 |
| CD (0.05) | 2.25 | 1.93 | 1.60 | 1.54 | 2.16 | 2.11 | 2.75 | 2.67 | | |

MTY: Marketable tuber yield; TTY: Total tuber yield

**Table 2. Mean performance of CP4409 in AICRP trials (2018-19 & 2019-20) at 75 and 90 days**

| Regions | Locations | Total tuber yield (t/ha) at 75 days | | | Total tuber yield (t/ha) at 90 days) | | |
|---|---|---|---|---|---|---|---|
| | | CP4409 | Kufri Lalit | Kufri Lalima | CP4409 | Kufri Lalit | Kufri Lalima |
| Northern plains | Hissar | 39.14 | 35.29 | 32.42 | 43.00 | 42.08 | 38.76 |
| | Jalandhar | 33.25 | 33.61 | 28.78 | 42.72 | 40.14 | 35.50 |
| | Modipuram | 37.41 | 31.97 | 33.23 | 46.22 | 48.30 | 45.83 |
| Central plains | Kanpur | 34.73 | 32.68 | 28.80 | 42.21 | 35.75 | 31.41 |
| Eastern plains | Bhubaneshwar | 20.01 | 15.18 | 15.42 | 24.85 | 18.93 | 16.91 |
| | Faizabad | 26.77 | 28.46 | 23.11 | 36.24 | 35.71 | 32.03 |
| | Kalyani | 25.80 | 20.71 | 23.01 | 32.63 | 32.59 | 31.01 |
| | Patna | 23.00 | 25.85 | 22.54 | 31.36 | 27.07 | 24.80 |
| Mean | | 30.01 | 27.97 | 25.91 | 37.40 | 35.07 | 32.03 |
| % Yield ± | | | 7.31 | 15.82 | | 6.65 | 16.77 |
| CD (0.05) | | Genotypes: 0.73, Genotype x location: 2.72) | | | Genotypes: 0.70, Genotype x location: 2.52 | | |

**Table 3. Mean performance of CP4409 in AICRP trials (2020-21) at 75 and 90 days**

| Regions | Locations | Total tuber yield (t/ha) at 75 days | | | | Total tuber yield (t/ha) at 90 days) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CP4409 | Kufri Manik | Kufri Lalit | Kufri Lalima | CP4409 | Kufri Manik | Kufri Lalit | Kufri Lalima |
| Northern plains | Hissar | 41.53 | 32.99 | 34.06 | 32.88 | 55.07 | 43.64 | 46.42 | 39.71 |
| | Jalandhar | 42.71 | 37.76 | 43.4 | 41.49 | 49.48 | 45.83 | 51.04 | 50.87 |
| | Modipuram | 29.69 | 30.79 | 27.92 | 29.19 | 43.26 | 38.32 | 43.94 | 38.12 |
| Central plains | Kanpur | 29.31 | 28.58 | 23.96 | 23.65 | 44.90 | 27.50 | 27.47 | 34.31 |
| Eastern plains | Bhubaneshwar | 13.38 | 8.45 | 10.38 | 10.82 | 20.46 | 13.72 | 12.25 | 16.71 |
| | Faizabad | 35.01 | 33.48 | 33.08 | 25.97 | 38.62 | 37.52 | 36.05 | 35.02 |
| | Kalyani | 36.62 | | 26.77 | 27.47 | 38.39 | | 27.36 | 30.24 |
| | Patna | 32.45 | 24.78 | 23.9 | 18.92 | 34.91 | 27.79 | 27.43 | 21.84 |
| Mean | | 32.59 | 28.12 | 27.93 | 26.30 | 40.64 | 33.47 | 34.00 | 33.35 |
| % Yield ± | | | 15.89 | 16.66 | 23.91 | | 21.40 | 19.54 | 21.84 |
| CD (0.05) | | Genotypes: 1.13, Genotype x location: 4.50 | | | | Genotypes: 0.92, Genotype x location: 3.57 | | | |

Manik (88%), Kufri Lalit (88%), and Kufri Lalima (93%).

**Crop duration (90 days):** The results pooled over eight locations, showed superior performance of advanced clone CP4409 (40.64 t/ha) by 21, 20, and 22% higher total tuber yield over Kufri Manik (33.47 t/ha), Kufri Lalit (34.00 t/ha) and Kufri Lalima (33.35 t/ha), respectively (**Table 3**). CP4409 produced nearly 89% marketable tuber yield as compared to Kufri Manik (91%), Kufri Lalit (89%), and Kufri Lalima (95%).

## Overall performance of advanced clone CP4409 in AICRP on Potato

**Crop duration (75 days):** In Northern plains, CP4409 (37.17 t/ha) produced 10, 9, and 14% higher total tuber yield over controls Kufri Manik (33.85 t/ha), Kufri Lalit (34.13 t/ha) and Kufri Lalima (32.49 t/ha), respectively. In Central plains, CP4409 (32.92 t/ha) produced 15, 11 and 22% higher total tuber yield over controls Kufri Manik (28.58 t/ha), Kufri Lalit (29.77 t/ha) and Kufri Lalima (27.09 t/

ha), respectively. In Eastern plains, CP4409 (26.83 t/ha) produced 21, 20 and 26% higher total tuber yield over controls Kufri Manik (22.24 t/ha), Kufri Lalit (22.44 t/ha) and Kufri Lalima (21.31 t/ha), respectively. Based on mean performance over 8 locations and years, advanced clone CP4409 (31.47 t/ha) yielded 12, 13 and 20% higher total tuber yield over Kufri Manik (28.12 t/ha), Kufri Lalit (27.74 t/ha) and Kufri Lalima (26.23 t/ha), respectively (**Table 4**). CP4409 produced nearly 92% marketable tuber yield than Kufri Manik (88%), Kufri Lalit (90%), and Kufri Lalima (90%).

**Crop duration (90 days):** In Northern plains (locations representing Punjab, Haryana, and western Uttar Pradesh), CP4409 (45.74 t/ha) produced 7, 2, and 12% higher total tuber yield over controls Kufri Manik (42.60 t/ha), Kufri Lalit (44.72 t/ha) and Kufri Lalima (40.99 t/ha), respectively. In Central plains (Kanpur representing central Uttar Pradesh), CP4409 (43.09 t/ha) produced 57, 31 and 33% higher total tuber yield over controls Kufri Manik (27.50 t/ha), Kufri Lalit (32.99 t/ha) and Kufri Lalima (32.38 t/ha), respectively. In Eastern plains (locations representing Orissa, Eastern Uttar Pradesh, West Bengal, and Bihar), CP4409 (31.94 t/ha) produced 21, 18 and 22% higher total tuber yield over controls Kufri Manik (26.34 t/ha), Kufri Lalit (27.14 t/ha) and Kufri Lalima (26.12 t/ha), respectively. The results pooled over eight locations and years, showed the superiority of advanced clone CP4409 (38.51 t/ha) by 15, 12 and 19% for higher total tuber yield over Kufri Manik (33.47 t/ha), Kufri Lalit (34.46 t/ha) and Kufri Lalima (32.48 t/ha), respectively (**Table 4**). CP4409 produced nearly 92% marketable tuber yield than Kufri Manik (91%), Kufri Lalit (92%), and Kufri Lalima (93%).

## Tuber dry matter content

At station trials, CP4409 contained nearly 18% tuber dry matter as compared to 18%

**Table 4. Mean performance of CP4409 in AICRP trials (2018-19, 2019-20 & 2020-21) at 75 and 90 days**

| Regions | Locations | Total tuber yield (t/ha) at 75 days | | | | Total tuber yield (t/ha) at 90 days) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CP4409 | Kufri Manik | Kufri Lalit | Kufri Lalima | CP4409 | Kufri Manik | Kufri Lalit | Kufri Lalima |
| Northern plains | Hissar | 40.27 | 32.99 | 34.88 | 32.57 | 47.03 | 43.64 | 43.53 | 39.08 |
| | Jalandhar | 36.40 | 37.76 | 36.88 | 33.02 | 44.97 | 45.83 | 43.77 | 40.62 |
| | Modipuram | 34.84 | 30.79 | 30.62 | 31.88 | 45.23 | 38.32 | 46.85 | 43.26 |
| | Mean | 37.17 | 33.85 | 34.13 | 32.49 | 45.74 | 42.60 | 44.72 | 40.99 |
| | % Yield ± | | 9.82 | 8.92 | 14.40 | | 7.39 | 2.30 | 11.61 |
| Central plains | Kanpur | 32.92 | 28.58 | 29.77 | 27.09 | 43.09 | 27.50 | 32.99 | 32.38 |
| | % Yield ± | | 15.19 | 10.58 | 21.52 | | 56.69 | 30.62 | 33.08 |
| Eastern plains | Bhubaneshwar | 17.88 | 8.45 | 13.19 | 12.45 | 22.66 | 13.72 | 15.59 | 16.81 |
| | Faizabad | 31.22 | 33.48 | 30.31 | 25.88 | 37.03 | 37.52 | 35.82 | 33.02 |
| | Kalyani | 30.98 | | 21.17 | 25.31 | 35.51 | | 29.98 | 30.63 |
| | Patna | 27.24 | 24.78 | 25.07 | 21.61 | 32.55 | 27.79 | 27.19 | 24.01 |
| | Mean | 26.83 | 22.24 | 22.44 | 21.31 | 31.94 | 26.34 | 27.14 | 26.12 |
| | % Yield ± | | 20.66 | 19.59 | 25.89 | | 21.23 | 17.66 | 22.28 |
| Grand mean | | 31.47 | 28.12 | 27.74 | 26.23 | 38.51 | 33.47 | 34.46 | 32.48 |
| % Yield ± | | | 11.91 | 13.46 | 19.99 | | 15.04 | 11.73 | 18.58 |

in Kufri Lalit and 19% in Kufri Lalima at 90 days (**Table 5**). Advanced clone CP4409 possessed comparable mean tuber dry matter content (%) of 17 and 19% at 75 and 90 days, respectively in comparison to controls Kufri Lalit (18 and 19%) and Kufri Lalima (19 and 20%) in multi-location AICRP on Potato trials during 2018-19 and 2019-20 (**Table 6**). During 2020-21 (**Table 7)**, this clone maintained 17 and 19% tuber dry matter content across the locations at 75 and 90 days as compared to Kufri Manik (16 and 18%), Kufri Lalit (17 and 18%) and Kufri Lalima (17 and 19%).

## Keeping quality

Advanced clone CP4409 was adjudged to be a very good keeper as it exhibited medium tuber dormancy (6-8 weeks), comparatively less total weight loss, rottage, sprout weight, and firm tuber appearance after 75 days of on-farm storage in station trials (**Table 8**). It clearly showed an advantage of very good keeping quality by having nil rottage and total weight loss (8.65%) as compared to the new red skin variety Kufri Lalit (2.60 and 9.34%). It had lower rottage and at par total weight loss when compared to the prevalent red skin variety Kufri Lalima (0.99 and 7.64%). Very good keeping quality of CP4409 will benefit small and marginal farmers, who are unable to store potatoes in cold stores. Normally, they store potatoes in traditional stores at their farm for a short period of about 75 days and sell their produce afterward in the market.

**Table 5. Tuber dry matter content of CP4409 at Modipuram, Meerut**

| Genotypes | Tuber dry matter (% | | | |
|---|---|---|---|---|
| | 2014-15 | 2015-16 | 2016-17 | Mean |
| CP4409 | 17.52 | 17.40 | 17.53 | 17.48 |
| Kufri Lalit | 17.93 | 18.15 | 18.38 | 18.16 |
| Kufri Lalima | 18.86 | 19.27 | 18.87 | 19.00 |
| CD (0.05) | 2.52 | 1.79 | 0.93 | 1.32 |

## Usage

The new early maturing variety Kufri Uday is suitable for table potatoes with attractive red ovoid tubers having shallow eyes, which leads to less peeling losses in comparison to Kufri Lalima and Kufri Sindhuri as both have round shaped tubers with deep eyes and their peeling losses are high (Luthra *et al.*, 2020 and Kumar *et al.*, 2014). Tubers of this variety seldom exhibit external/internal defects and are not susceptible to skin damage at harvest. Its tubers are easy to cook (15-20 minutes)

**Table 6. Tuber dry matter (%) content in AICRP trials (pooled over 2018-19 & 2019-20).**

| Regions | Locations | 75 days | | | 90 days | | |
|---|---|---|---|---|---|---|---|
| | | CP4409 | Kufri Lalit | Kufri Lalima | CP4409 | Kufri Lalit | Kufri Lalima |
| Northern plains | Hissar | 14.64 | 15.87 | 16.99 | 16.75 | 16.09 | 20.20 |
| | Jalandhar | 15.82 | 15.71 | 18.12 | 16.50 | 16.83 | 18.73 |
| | Modipuram | 14.04 | 15.51 | 18.17 | 15.80 | 15.73 | 19.74 |
| Central plains | Kanpur | 20.73 | 21.21 | 21.28 | 23.52 | 24.32 | 24.25 |
| Eastern plains | Bhuwabneshwar | 18.38 | 19.36 | 19.24 | 18.11 | 18.72 | 19.10 |
| | Faizabad | 17.37 | 17.43 | 17.32 | 18.43 | 18.68 | 18.38 |
| | Kalyani | 20.18 | 18.50 | 21.44 | 23.46 | 21.55 | 22.46 |
| | Patna | 16.67 | 17.05 | 15.47 | 17.60 | 17.65 | 17.88 |
| Mean | | 17.23 | 17.58 | 18.50 | 18.77 | 18.70 | 20.09 |
| CD (0.05) | | Genotypes: 0.16, Genotype x location: 0.52 | | | Genotypes: 0.26, Genotype x location: 0.61 | | |

**Table 7. Tuber dry matter (%) content in AICRP trials during 2020-21**

| Regions | Locations | 75 days | | | | 90 days | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CP4409 | Kufri Manik | Kufri Lalit | Kufri Lalima | CP4409 | Kufri Manik | Kufri Lalit | Kufri Lalima |
| Northern plains | Hissar | 14.70 | 14.63 | 15.60 | 16.75 | 16.15 | 15.78 | 16.30 | 17.60 |
| | Jalandhar | 16.25 | 15.75 | 16.75 | 17.00 | 18.50 | 17.73 | 18.00 | 19.00 |
| Central plains | Kanpur | 17.08 | 16.98 | 17.73 | 17.08 | 19.78 | 18.85 | 20.60 | 20.03 |
| Eastern plains | Bhubaneshwar | 16.53 | 15.92 | 16.35 | 18.40 | 18.21 | 17.08 | 17.78 | 18.95 |
| | Faizabad | 17.30 | 17.71 | 16.30 | 17.50 | 18.10 | 18.89 | 17.09 | 18.40 |
| | Kalyani | 18.57 | - | 18.46 | 18.83 | 22.28 | - | 21.58 | 20.29 |
| | Patna | 15.40 | 14.63 | 15.90 | 16.30 | 16.93 | 16.87 | 16.90 | 16.67 |
| Mean | | 16.55 | 15.94 | 16.73 | 17.41 | 18.56 | 17.53 | 18.32 | 18.71 |

**Table 8. Keeping quality (mean of 4 years) at Modipuram, Meerut**

| Genotypes | Dormancy | Sprouting (%) | | Loss due to sprouting (%) | Loss due to rottage (weight basis) (%) | Physiological weight loss (%) | Total weight loss (%) |
|---|---|---|---|---|---|---|---|
| | (<or> than 6 weeks | At 6 weeks | At 75 days | | | | |
| CP4409 | 6-8 weeks | 63.06 | 95.00 | 0.65 | 0.00 | 8.00 | 8.65 |
| Kufri Lalit | >10 weeks | 33.80 | 60.88 | 0.10 | 2.60 | 6.64 | 9.34 |
| Kufri Lalima | >10 weeks | 2.25 | 30.06 | 0.06 | 0.99 | 6.60 | 7.64 |

and cooked/boiled tubers are free from any kind of discolouration. The variety possesses a pleasant flavour, mealy texture, and good organoleptic taste. Thus, the desirable tuber characters, good keeping, and culinary quality of this variety will favour its acceptance.

## Disease resistance

CP4409 has field resistance to late blight (AUDPC: 398; lesion area: 4.49 $cm^2$) as compared to the red skinned varieties like Kufri Lalit (AUDPC: 550; lesion area: 6.68 $cm^2$) and Kufri Lalima (AUDPC: 570; lesion area: 4.70 $cm^2$), when investigated under field conditions and through standard detached leaf method (Lal *et al.* 2020), respectively (**Table 9**).

**Table 9. Late blight at Modipuram, Meerut**

| Genotypes | Field screening | | Detached leaf | |
|---|---|---|---|---|
| | AUDPC | rAUDPC | Lesion area ($cm^2$) | Grading |
| CP4409 (3*) | 398 | 0.20 | 4.49 | MR |
| Kufri Lalit (3*) | 550 | 0.28 | 6.68 | S |
| Kufri Lalima (2*) | 570 | 0.29 | 4.70 | MR |

*Number of years screened; Grading: Lesion area ($cm^2$): Up to 1.0- Highly resistant (HR); 1.1 to 2.5- Resistant (R); 2.51-5.0- Moderately resistant (MR), > 5.0 –Susceptible (S)
AUDPC (< 250):HR; AUDPC (251-350):R; AUDPC (351-650):MR; AUDPC (651-1200):S; AUDPC (>1200):HS

## Crop management

Kufri Uday is capable of producing 36-38 t/ha total tuber yield following the normal agronomical schedule of potato crops.

***Planting time:*** Optimum planting time in North-Indian plains remains between the second fortnights of October to the first fortnight of November when the daily maximum day temperature comes down to around 32°C.

***Seed rate:*** 35-40 q/ha. *Seed size*: 40-60 g. Seed tubers are to be taken out from the cold store at least 10 days before planting. Exposure of seed bags in direct sunlight is to be avoided as it may result in rottage due to sudden

exposure to high temperatures. Spreading of tubers in thin layers under shade in diffused light leads to proper sprouting and allows sprouts to become 0.5-1.0 cm long, thick, and green. Sprouted tubers are to be taken in seed trays or baskets for planting to avoid sprout damage.

***Spacing:*** Plant spacing at 20 cm in 60 cm rows provides optimum tuber size distribution for seed or table potatoes.

***Fertilizer:*** Fertilizer doses have been worked out after field experimentation at Modipuram. CP4409 responded up to 240 N, 30 $P_2O_5$, and 120 $K_2O$ kg/ha, respectively for 90 days of crop duration of ware potatoes. For seed crops, 150 kg N, 30 kg $P_2O_5$, and 120 kg $K_2O$ per hectare can be applied. Green manuring before the potato crop is beneficial for crops in several ways including crop nutrition. At, planting 10-15 t/ha well rotten FYM may also be applied to provide seed bed a better tilth and nutrition to the potato crop. These crop management practices shall reduce the approximately one-third dose of nitrogen and half doses of phosphorus and potassium. Thus, half-adjusted doses of N and full-adjusted doses of $P_2O_5$ and $K_2O$ should be applied at planting. The remaining half-adjusted dose of N should be applied 20-25 days after planting i.e. at the time of inter-cultivation and earthing up. Nutrient management in different agroecologies may differ, so, the regional recommendation may be fine-tuned and adopted for obtaining optimum productivity of this clone.

***Irrigations:*** Pre-sowing irrigation is done to ensure uniform emergence. If this is not given then the first irrigation should be done 4-6 days after planting. Post planting irrigations are kept light and applied subsequently at 7-10 days intervals in sandy loam soil and 10-12 days in heavy soil. Potato ridges must not be submerged under water in any case and arrangements for drainage should also be developed keeping unseasonal rains in view during the crop season.

***Plant Protection Measures:*** For management of cutworms, white grubs, beetles, and leaf eating caterpillars, apply cartap hydrochloride 4G @20 kg/ha during earthing-up. It will also take care of sucking pests like leaf hoppers and aphids. For seed crops, place yellow sticky traps (15x30 $cm^2$ size) just above the canopy height @ 60 traps/ha at equidistance from each other for mass trapping of white flies/aphids. Seed treatment is done with imidacloprid (200SL) @ 0.04% (4 ml/10 l water) for 10 minutes before planting. The first spray of imidacloprid (200SL) @ 0.03% (3 ml/10 l water) is completed at 85% crop emergence followed by a second spray with thiamethoxam (25 WG) @ 0.05% (5 gm/10 l water) 10-15 days after the first spray. Although the variety is moderately resistant to late blight, prophylactic spray just at the time of canopy closure with mancozeb or propineb or chlorothalonil @ 0.2% (2 gm/l water) followed by need based application of cymoxanil + mancozeb or dimethomorph + mancozeb or fenamidone + mancozeb @ 0.3% (3 gm/l water) is required for effective management of late blight. Insecticide sprays are not required in the case of table crops and integrated pest and disease management recommended by the institute should be followed (Rawal *et al*., 2021).

***Harvesting:*** Irrigation should be stopped 10-12 days before haulm killing and harvesting may be done 10-15 days after haulm cutting at proper soil moisture. After harvest, produce should be kept under shade in heaps covered with 30 cm thick available straw or crop residue for 10-15 days. Both of these measures shall help in curing tuber skin. All damaged and rotten tubers are removed and graded for fetching better prices in the market. Potatoes are packed in 45-50 kg capacity gunny or

leno bags and labeled either for selling in the market or storing in cold storage (Rawal *et al*., 2021).

## ADAPTABILITY

Kufri Uday has performed well in multi-location trials conducted under AICRP on Potato and has been recommended for cultivation in North-Indian plains. Thus, the variety Kufri Uday can easily be grown in Punjab, Haryana & Uttar Pradesh (Northern plains); Central Uttar Pradesh (Central plains) and Bihar, Orissa, West Bengal, and Eastern Uttar Pradesh (Eastern plains).

## CONCLUSION

Due to early maturity, high yield, and very good keeping quality, Kufri Uday can serve as a better choice for farmers and consumers, where red skinned potatoes are preferred. Kufri Uday export potential can also be explored in Bangladesh, Bhutan, Nepal, Pakistan and Philippines, where red skinned tubers are traditionally preferred (Pandey *et al.* 2000 and Luthra *et al.* 2004).

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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# ADAPTIVE MODELS FOR DETERMINING CROPLAND SUITABILITY AND TOTAL HARVEST PREDICTION FOR POTATO USING IOT

**Rindra Yusianto[1]*, Guruh Fajar Shidiq[2], Herwin Suprijono[3] and Marimin[4]**

**ABSTRACT: Potatoes are Indonesia's fourth largest food agro-industrial and leading horticultural commodities traded internationally. In 2021, the needs of the potato industry will only be met by 85.93%. This study aims to provide recommendations for adaptive models for increasing productivity based on the suitability of agricultural cropland and predicting total harvest using IoT. We modified the multi-thresholding method by installing an $SHT_{15}$ sensor to measure temperature. We also installed rain gauge sensors and analyzed the spatial perspective. Using a drone quadcopter, we perform image processing and mapping to predict the total harvest. The research sample used a random of 12 grids in an agricultural area in Wonosobo, Indonesia. The results showed that the most suitable agricultural cropland was 11.05%, suitable was 22.9%, and cropland with several inhibiting factors was 62.01%. The most convenient location is at the coordinates 7° 15′ 12.1″ S latitude, 109° 55′ 27.5″ E longitude in Kejajar, Wonosobo District. The results also showed an average harvest of 13.79 t $ha^{-1}$. This model can predict an increase in yields with a production prediction of 72,765 t $year^{-1}$ and an accuracy rate of 89.35%. In addition, to balance supply and demand, this model recommends an increase in production by 30% and fulfillment from other regions by 31%.**

**KEYWORDS:** Cropland suitability; IoT; Potato; Spatial perspective; Total harvest prediction

## INTRODUCTION

Potatoes are Indonesia's fourth largest food agro-industrial commodity and leading horticultural commodities traded internationally, with good growth characteristics in the highlands of 1,100–1,300 m asl, humidity 85–90%, temperature 15.5–18.5 degrees Celsius, and rainfall 300-310 millimeters (Yusianto *et al*., 2021; Raja *et al*., 2020). The habit of farmers reduces productivity, planting potatoes on all the cropland they have. Based on the Indonesia Central Bureau of Statistics, the raw material needs for industrial potatoes in Central Java, Indonesia, ranging from 300-325 t $day^{-1}$. Meeting industrial needs requires a good supply strategy, and one of the strategies is the suitability of agricultural cropland. In this study, we determined the most suitable locations for potato cultivation and then calculated the estimated average and total yields. Cropland suitability evaluation needs to be done. This evaluation is a cultivation requirement, namely by measuring the suitability of agricultural cropland, assessing the suitability of alternative land uses, and comparing growth requirements, characteristics of agricultural cropland, and quality, which is evaluated by utilizing the potentially available resources (Tesfay *et al*., 2017). The suitability of agricultural cropland is to measure how the quality of agricultural land can meet land use requirements, including physical and climatic factors (Singh

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& Sandhu, 2022). Potato cultivation that meets industrial needs must be on suitable cropland—determination of the suitability of agricultural cropland to determine the potential for developing this agro-industrial commodity.

Cultivating potatoes on suitable agricultural cropland can meet the needs of industrial raw materials, reduce the risk of post-harvest losses, and increase productivity (Hardjomidjojo *et al*., 2022). The current problem is that most of the agricultural cropland in Indonesia has been converted into residential land. In addition, rapid population growth significantly affects the use of agricultural land. Therefore, decision-makers need to optimize land use so that the cultivation of agricultural commodities, including potatoes, can grow sufficiently with high productivity. In addition, decision-makers must consider various factors that influence this, namely physical and climatic factors. Rykaczewska (2017) and Yusianto *et al*. (2020) research shows that physical characteristics, namely land slope, elevation, and soil texture, and climatic factors, namely humidity, temperature, and rainfall, affect land suitability.

The Internet of Things (IoT) is a precision agricultural technology that can help meet data needs and provide information on industrial raw materials and global food security (Ramankutty *et al*., 2018). IoT can control crop quality, cropland suitability, and production (Marcu *et al*., 2019). Foughali *et al*. succeeded in developing IoT integration with DSS to increase agricultural production (Foughali *et al*., 2019). IoT can also retrieve physical and climate data using sensors and input it into machine learning algorithms (Araby *et al*., 2019). In their study, the Node-MCU and $DHT_{11}$ temperature and humidity sensors collected temperature data. Electronic control using IoT supports real-time data collection on several conditions that precision agriculture requires, such as physical change data, spatial conditions, and climate data (Qi *et al*., 2016). Analysis of spatial requirements using GIS can provide spatial data and visual data representation of the research area. The spatial analysis also allows the presentation of information more specifically to help decision-makers make more appropriate decisions than classical analysis. GIS and IoT can handle spatial analysis with zoning and land use planning. The elaboration of spatial analysis using GIS and IoT can combine time with interactive decision-making forms, where IoT has determined the optimal planting coordinates by evaluating land suitability. In addition, IoT also relates location data quantitatively when performing spatial analysis and predicting total harvest.

In the last ten years, determining agricultural cropland suitability has become increasingly complex. Standard statistical techniques will not be able to solve this difficult problem, including predicting the total harvest. Therefore, at this time, farmers need IoT as an innovative precision farming technology (Kiani and Seyyedabbasi, 2018).

Most of the previous studies have discussed the implementation of IoT in precision agriculture. However, they should have addressed modifications to land suitability models and harvest predictions with IoT and spatial analysis considering coordinates (X, Y) and physical factors. This study aims to provide recommendations for adaptive models to predict cropland suitability and total harvest using IoT. We modified the multi-thresholding method by installing an $SHT_{15}$ sensor to measure temperature and humidity. We also installed rain gauge sensors and analyzed the spatial perspective. The research sample used a

random grid of 12 grids in an agricultural area in Wonosobo District, Indonesia.

## MATERIALS AND METHODS

### Description of the Study Area

We conducted this experiment in 15 zones of Wonosobo Regency, Indonesia, during the 2022 growing season. The area is 120 kilometers from Semarang in the southwest region of Indonesia. Geographically, this area is located at 7° 21' S, 109° 53' E, at an altitude of 250 - 2,250 meters above sea level (masl) (Figure 1).

The average elevation of the 14 zones is 674.81 masl, with the highest peak of 1,378 m and the lowest of 272 m. The soil texture is mostly andosol, podzol, and regosol. The average slope is 8–13% wavy or steep, with an average temperature above 20 degrees Celsius. The average humidity is 80–90%, and the average rainfall is above 300 millimeters month$^{-1}$.

### Experimental Materials

The most significant need for raw material for Central Java, Indonesia industrial potatoes is for French fries, as much as 115 t day$^{-1}$. In addition, potato chips are 95 t day$^{-1}$, frozen potatoes are 52 t day$^{-1}$, and the remaining 63 t day$^{-1}$ are to meet the needs for starch, concentrate, and biodegradable packaging (Balitsa, 2014). Table 1 shows the potato-based industry, varieties, and the number of industrial potatoes needed per year.




*Figure 1. Map of study area*

The biggest industrial demand for potatoes in Central Java, Indonesia, in 2022 is for raw material for French fries, 35% with Atlantic and median varieties. At the same time, the smallest requirement is 16% for frozen potato raw materials.

### Experimental framework

We modified an adaptive model to determine cropland suitability and predict total harvest using the $SHT_{15}$ sensor and rain gauge. Then, we conducted a spatial analysis with four variables: altitude, soil texture, temperature, and rainfall. The research sample is 12 grids using a random grid base, and we get four class intervals. The cropland unit map uses a scale of 1: 25,000 using the overlay technique. To produce elevation and soil texture maps, we analyzed the physical and climatic factors of 12 zones in Wonosobo, Indonesia. We also collect data on soil texture, temperature, and rainfall (Figure 2).

We classify the class criteria and cropland suitability level intervals. We classify them into suitability classes ($S_1$, $S_2$, $S_3$, and NS). Then, we carried out a spatial analysis, with the final result being a land suitability evaluation. We determined sample points based on land units and used grid intervals of 1.5 km across 12 grids. We collect data

**Table 1. The number of Central Java, Indonesia industrial potatoes needed per year**

| Varieties | Industry | Requirement (tons year$^{-1}$) | Percentage |
|---|---|---|---|
| Atlantic, Median | French Fries | 41,400 | 35% |
| Atlantic, Maglia, Amabile | Chips | 34,200 | 29% |
| Atlantic, Median | Frozen | 18,720 | 16% |
| Atlantic, Median | Other | 22,680 | 19% |

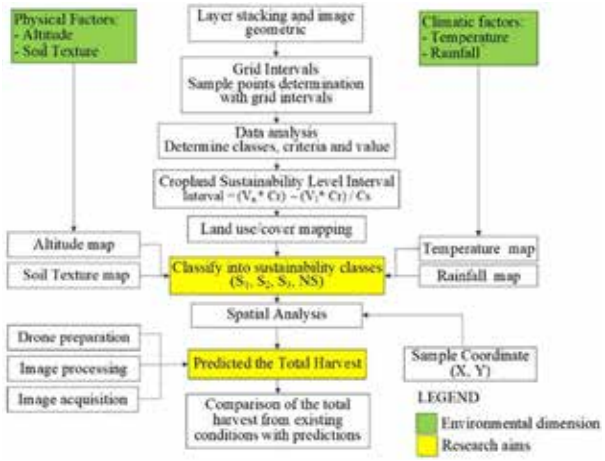



*Figure 2. Experimental framework*

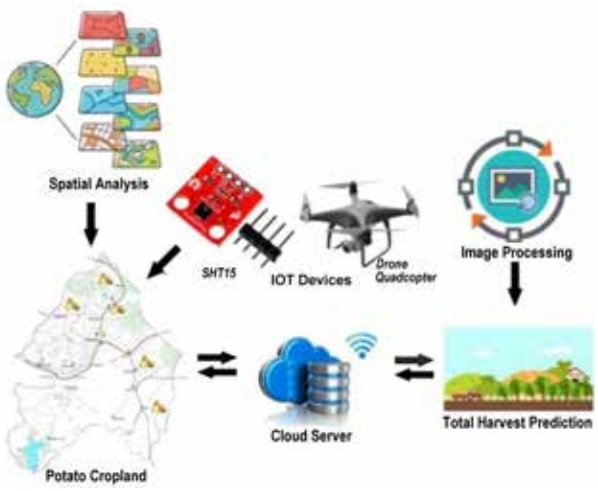



*Figure 3. The system architecture*

from IoT from $SHT_{15}$ and rain gauge sensors with a calibration accuracy of ± 0.4 @ 5–40 degrees Celsius. The sensors installed in the sample area will send data 24 hours daily. After determining the most appropriate coordinates, we perform image processing and mapping to predict the total harvest using a drone quadcopter. The system architecture of this study consists of two main activities: cropland suitability and full yield prediction (Figure 2).

## Class Criteria

Research by Mailangkay *et al.* (2012) has shown that altitude significantly affects the number of potato tubers and increases production capacity. Based on the average value, they do not recommend cultivation at sizes below 750 masl. Their research indicated that tuber weight and productivity were deficient for Granola and Supejhon varieties at that altitude. The highlands and mountains, where the temperature varies and often changes dramatically, significantly affect productivity due to land suitability for agricultural commodities (Porter *et al.*, 2015). Yusianto *et al.* research (2021) state that China accounts for 26.3% of world potato production. One of the keys to success is the mechanization and selection of suitable agricultural land. In the study, they explained that China mass-produced potatoes in the Guyuan region, Hebei, which has a proper soil texture and climate.

We arranged the class criteria and gave a score of 4 for excellent, 3 (good), 2 (rather bad), and 1 (bad) (Table 2). The criteria consist of physical factors: altitude, soil texture, climate, temperature, and rainfall. We compiled each score for each class criterion based on research by (Hardjomidjojo *et al.* 2022; Yusianto *et al.* 2021).

**Table 2. Classes criteria for potato plants**

| Value | Classes | Altitude (masl) | Soil texture | Temperature | Rainfall |
|---|---|---|---|---|---|
| 1 | Excellent | 1,300 - 2,700 | Andosol | 15.6–17.8 | >300 |
| 2 | Good | 500 -1,299 | Regosol | 17.7–20.0 | 200–300 |
| 3 | Rater Bad | 199 - 499 | Podzol | 20.1–25.0 | 60–199 |
| 4 | Bad | < 199 | Latosol | >25.0 | <60 |

## Suitability Level Interval

We analyzed cropland suitability intervals for Atlantic, Median, Maglia, and Amabile varieties as industrial raw materials (Equation (1)).

$$SLI = \frac{(V_n \times Cr) - (V_1 \times Cr)}{Cs} \quad \text{......(1)}$$

Where: SLI- suitability level interval, $V_n$- highest class criteria value, $V_1$- lowest class criteria value, Cr- several measures, Cs- several class intervals.

We used a multi-criteria measure to determine the suitability intervals of four criteria (physical and climatic factors) and four classes interval. We arrange suitability level. Using Equation (1), we get a class interval of 4 with the lowest class criterion value of 4 (Table 3).

## Spatial Analysis

Based on 12 sample points, the average height is 778.42 masl. Most soil texture is regosol, while there is no latosol texture. The average temperature is 25.25 degrees Celsius. At the same time, $P_1$ has the lowest average temperature, 19 degrees Celsius. At the same time, the average rainfall is 305.06 millimeters month$^{-1}$ or an average of 1,000 millimeters year$^{-1}$, where the little rain is at $P_7$, which is 247.50 millimeters month$^{-1}$ (Table 4).

For altitude, we found that the $P_1$ had an altitude of 1,378 masl. As for the criteria for soil texture, we obtained the dominant surface, regosol. We mapped the altitude to an altitude map and texture map in the 12 sample areas. The lowest average temperature is 17 degrees Celsius—the rainfall, with an average of over 305 millimeters month$^{-1}$. We also map temperature and rain into a temperature map and rainfall map (Figure 4).

Yield prediction accuracy is essential for many issues in agriculture, national food

**Table 3. Cropland suitability level interval**

| Suitability level | Class | Total value | Description |
|---|---|---|---|
| The Most Suitable | $S_1$ | >=16.0 | Cropland is in perfect condition. |
| Suitable | $S_2$ | 12.0 – 16.0 | Cropland with a few inhibiting factors. |
| Rather Suitable | $S_3$ | 8.0 – 12.0 | Cropland with several inhibiting factors. |
| Unsuitable | NS | 4.0 – 8.0 | Cropland with a deplorable condition. |

**Table 4. Spatial analysis for four criteria**

| Code | Location | Latitude | Longitude | Altitude (masl) | Soil Texture | Temperature Degrees Celsius | Rainfall (millimetres month$^{-1}$) |
|---|---|---|---|---|---|---|---|
| $P_1$ | Kejajar | 7°14′11.8″S | 109°56′29.7″E | 1,378 | Andosol | 17 | 341.00 |
| $P_2$ | Garung | 7°16′52.1″S | 109°56′37.2″E | 1,019 | Andosol | 23 | 326.83 |
| $P_3$ | Mojotengah | 7°17′31.6″S | 109°52′31.7″E | 860 | Andosol | 24 | 317.75 |
| $P_4$ | Kertek | 7°19′35.8″S | 109°59′28.2″E | 825 | Regosol | 22 | 275.00 |
| $P_5$ | Kalikajar | 7°22′38.5″S | 109°59′33.6″E | 815 | Regosol | 20 | 351.92 |
| $P_6$ | Wonosobo | 7°20′46.1″S | 109°55′07.3″E | 744 | Regosol | 26 | 299.81 |
| $P_7$ | Watumalang | 7°21′33.2″S | 109°52′36.5″E | 910 | Regosol | 24 | 247.50 |
| $P_8$ | Kaliwiro | 7°27′17.7″S | 109°46′49.2″E | 360 | Podzol | 27 | 260.75 |
| $P_9$ | Kalibawang | 7°29′00.7″S | 109°55′03.1″E | 626 | Regosol | 26 | 297.60 |
| $P_{10}$ | Sapuran | 7°26′32.4″S | 109°59′14.1″E | 760 | Regosol | 26 | 299.89 |
| $P_{11}$ | Kepil | 7°33′08.2″S | 110°00′45.2″E | 522 | Podzol | 27 | 347.08 |
| $P_{12}$ | Sukoharjo | 7°23′49.2″S | 109°46′36.1″E | 522 | Podzol | 27 | 347.08 |

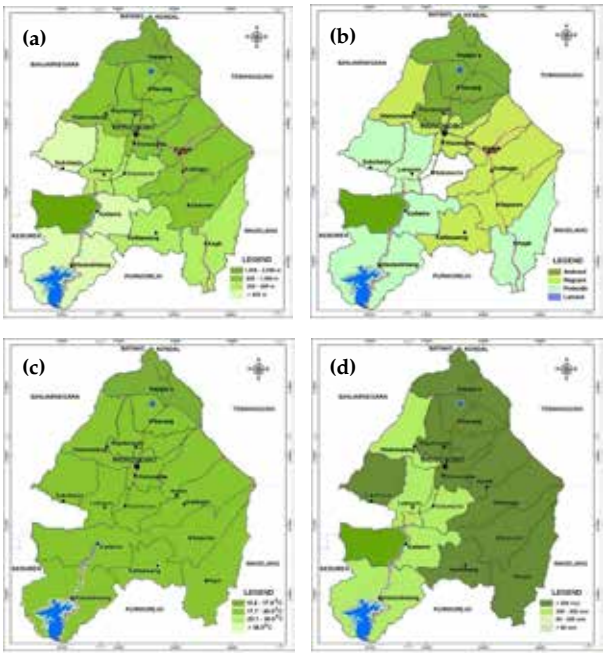



*Figure 4. Altitude (a), soil texture (b), temperature (c), rainfall map (d)*

policy, and international trade in agro-industrial commodities. So that various methods and approaches are used to predict crop yields, including the application of satellite imagery (Kim *et al*., 2019). With the support of IoT sensors, satellite remote sensing techniques, and image processing can transmit data over a large area continuously. This technique helps decision-makers make decisions and provides more accurate predictions of outcomes.

In this study, we obtained images of the planting area from a quadcopter drone. We mapped the cropland using a modified multi-thresholding method. We then group the image acquisition data into 24 blocks. The place we imaged per point is one hectare of cropland labeled $A_{01}$ through $F_{04}$. To calculate the predicted total harvest, we use Equation (2).

$$Th = \frac{Pcp}{Ts} \quad \text{.....(2)}$$

Where: Th- Prediction of total harvest, Pcp- production capacity prediction, Ts- total sample area.

Mapping the spatial distribution of agricultural land can increase accuracy when predicting crop yields. We compared the total harvest prediction results with existing conditions to ensure the accuracy of the total harvest prediction (Equation (3)).

$$Ar = \frac{Thp}{Existing\ condition} \times 100 \quad \text{.....(3)}$$

Where: Ar- Accuracy rate, Thp- Total harvest prediction.

# RESULTS AND DISCUSSION

## Spatial analysis for each criterion

We provide recommendations for adaptive models to determine agricultural land suitability, especially agricultural commodities and predict the total harvest using IoT. We also analyze the spatial perspective and modify the multi-thresholding method by installing an $SHT_{15}$ sensor to measure temperature and a rain gauge sensor. We use four criteria (Table 5) and assign a weight value using Equation (1) for each standard. Based on the cropland suitability level interval, we get a spatial analysis for each criterion.

Based on spatial analysis, 3 locations correspond to a total score of 13. Nine areas are rather suitable, with a total score of 9-11, and 1 very suitable location, with a total score of 16.

## The cropland suitability area

Using spatial analysis and geoprocessing using a geo-segregation analysis, we get the result that of the 12 research sample locations, we compiled the distribution of the suitability cropland area (Figure 5). The suitability level of 8.01% belongs to the very suitable category scattered in the north of the research area and centered at coordinates 7° 14′ 11.8″ S latitude, 109° 56′ 29.7″ E longitude. Then 24.96% belongs to the suitable type, which is spread over the top and middle of the research area. Meanwhile, 67.03% belonged to the rather suitable category. It has scattered

**Table 5. Spatial analysis for each criterion**

| Code | Altitude | | Texture | | Temperature | | Rainfall | | Total Value | Result |
|---|---|---|---|---|---|---|---|---|---|---|
| | m ASL | V[1] | Texture | V[1] | $^0$C | V[1] | mm / month | V[1] | | |
| $P_1$ | 1,378 | 4 | Andosol | 4 | 19 | 3 | 341.00 | 4 | 16 | Very Suitable |
| $P_2$ | 1,019 | 3 | Andosol | 4 | 23 | 2 | 326.83 | 4 | 13 | Suitable |
| $P_3$ | 860 | 3 | Andosol | 4 | 24 | 2 | 317.75 | 4 | 13 | Suitable |
| $P_4$ | 825 | 3 | Regosol | 3 | 22 | 2 | 275.00 | 3 | 11 | Rather Suitable |
| $P_5$ | 815 | 3 | Regosol | 3 | 20 | 3 | 351.92 | 4 | 13 | Suitable |
| $P_6$ | 744 | 3 | Regosol | 3 | 26 | 2 | 299.81 | 3 | 11 | Rather Suitable |
| $P_7$ | 910 | 3 | Regosol | 3 | 24 | 2 | 247.50 | 3 | 11 | Rather Suitable |
| $P_8$ | 360 | 2 | Podzol | 2 | 27 | 2 | 260.75 | 3 | 9 | Rather Suitable |
| $P_9$ | 626 | 3 | Regosol | 3 | 26 | 2 | 297.60 | 3 | 11 | Rather Suitable |
| $P_{10}$ | 760 | 3 | Regosol | 3 | 26 | 2 | 299.89 | 3 | 11 | Rather Suitable |
| $P_{11}$ | 522 | 3 | Podzol | 2 | 27 | 2 | 347.08 | 4 | 11 | Rather Suitable |
| $P_{12}$ | 522 | 3 | Podzol | 2 | 27 | 2 | 347.08 | 4 | 11 | Rather Suitable |

Where: V[1]- Value.

in the center of the map and partly to the south of the study area.

Based on the spatial distribution, we validate the spatial region. Regions with suitable criteria have the most significant production, 447,060 t year$^{-1}$ (Table 6). Next, we estimate the amount of harvest by using data from drone quadcopters, IoT, and sensors. Then, we abuse land suitability results and spatial distribution maps to calculate the expected yield. In Indonesia, 80–85% of total potato production is vegetable potatoes with the Granola L. variety, while potatoes for industrial raw materials are only around 15–20%.

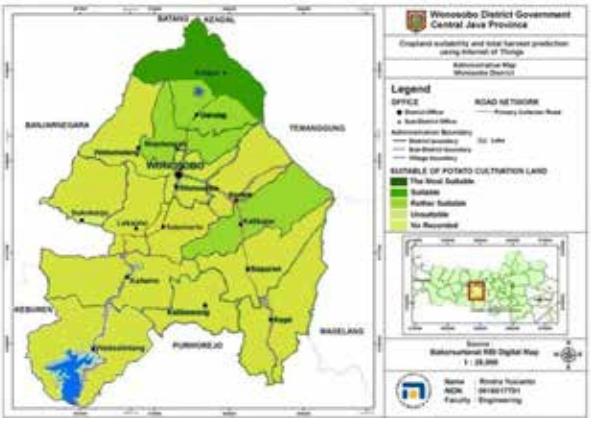



*Figure 5. Spatial distribution cropland suitability area*

The most suitable location is Kejajar ($P_1$) at coordinates 7° 14′ 11.8″ S latitude, 109° 56′ 29.7″ E longitude, so to meet industry needs, we suggest that decision-makers prioritize this location. However, we were still able to optimize several areas with

**Table 6. The existing production**

| Location | Latitude | Longitude | Existing Production (t) | Granola L 85% | Industry 15% |
|---|---|---|---|---|---|
| Kejajar | 7°14′11.8″S | 109°56′29.7″E | 447,060 | 380,001 | 67.059 |
| Garung | 7°16′52.1″S | 109°56′37.2″E | 74,240 | 63,104 | 11,136 |
| Kalikajar | 7°22′38.5″S | 109°59′33.6″E | 19,683 | 16,731 | 2,952 |
| Mojotengah | 7°17′31.6″S | 109°52′31.7″E | 905 | 769 | 136 |
| | | Total | 541,888 | 460,605 | 81,283 |

the criteria of several inhibiting factors, namely Garung ($P_2$), Kalikajar ($P_5$), and Mojotengah ($P_3$).

## Image acquisition

We develop predictions of total harvest based on cropland suitability. Then, we modify the multi-thresholding and separate the pixel intensity values into several regions. We obtained data and the image from a quadcopter drone with a flying area at 12 coordinate points that we have determined using the deploy smartphone application. In this modification, we register the site to determine the flight altitude, overlap, shooting direction, and shooting location according to points in 12 grids. After setting, the quadcopter drone will send an image map. We acquired the image just before harvest, 90 days after planting (Figure 6).

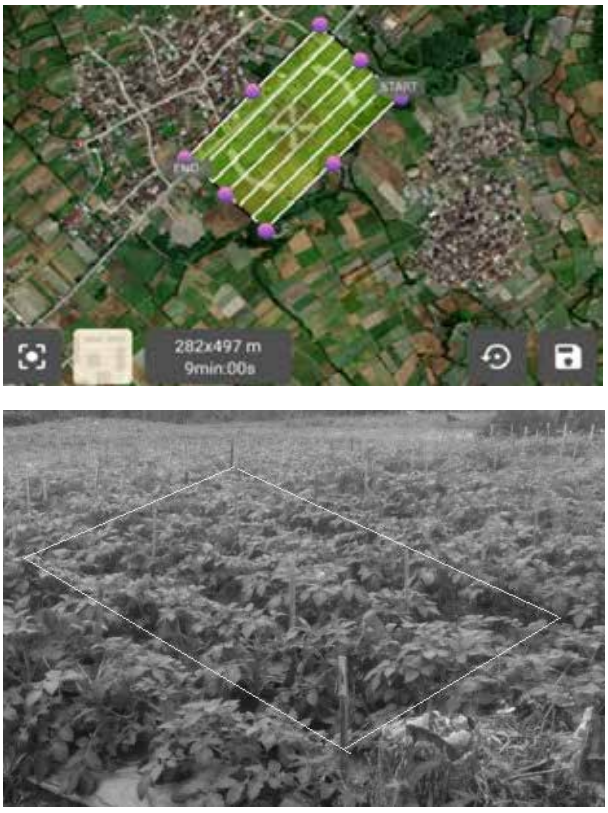



*Figure 6. Image acquisition*

## Image segmentation

We converted the last image we modified to grayscale. We map the land into 12 grids based on grid-based. We then modify the planting age data on each grid with a segmentation technique. We extract the brownish-green components in the leaf image and then modify the original image.

Furthermore, we converted to multi-thresholding because, in the case of agriculture, especially potatoes, we could not distinguish in detail and significantly the color and appearance of the leaves. Leaves that are still green and leaves that are ready to harvest are almost the same. Therefore, we modified the threshold values for this multi-threshold method to be 0–100 and 100–250. In this research, we use a leaf image. Our images are modified based on the age of the plants, the color of the leaves, and the background objects in each grid to make image processing easier (Figure 7). Then we segmented the region using modified multi-thresholding; we defined area one as the background image and area two as the leaf image.

So that the color of the young leaves and those ready for harvest are slightly different, we modified the threshold value in the multi-thresholding process. The proportional value that we give is between 100 and 250. As for the pixel intensity in region one, we give a value between 0–100. Whereas in region two, we give a score between 100–250.

segment_1 = imquantize (green, [0 100]);

RGB = label2rgb (segment_1);

number, imshow (RGB)

We calculate the segmentation result using the percentage of segmentation pixels.

## Total harvest comparison

Before comparing yields, we grouped the sample image acquisition into 24 sample

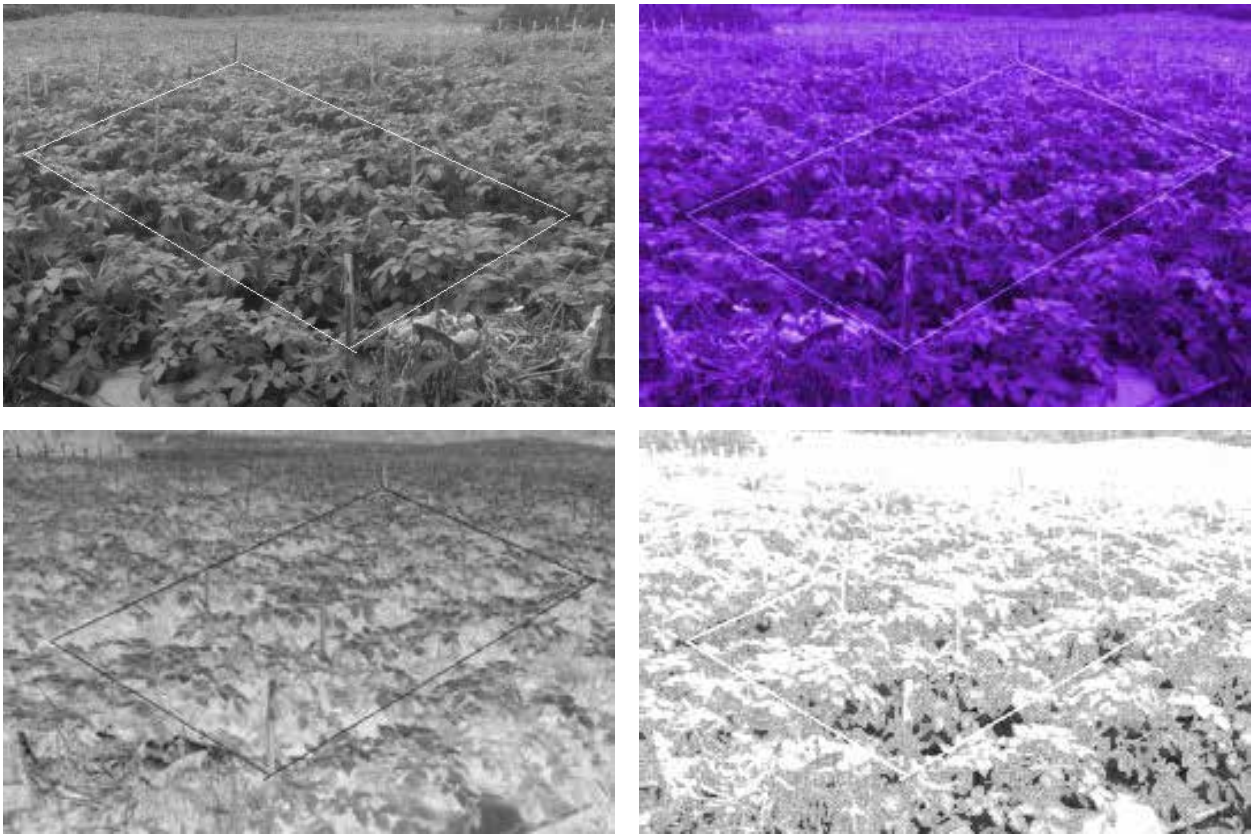


*Figure 7. Modified and image segmentation*

blocks (Table 7). We provide an index from $A_{01}$ to $F_{04}$. Then we process the pixel data for each region into a percentage of pixels. After that, we weighed the samples for each harvest.

The results showed that the average sample weight was 862.12 kg (0.862 t), with an average yield of 13.79 t $ha^{-1}$. Then we compared the condition of the crop yields in the 24 blocks with the predicted harvest using spatial analysis (Table 8).

## The Scenario of an alternative strategy

Based on the analysis of the spatial distribution of predicted yields, we found four suitable areas, namely Kejajar ($P_1$), Garung ($P_2$), Mojotengah ($P_3$), and Kalikajar ($P_5$). We calculate the existing production and predicted total harvest in the four areas (Table 9).

**Table 7. The result of weighing harvest data**

| Sample Block | Weight (kg) | Sample Block | Weight (kg) | Sample Block | Weight (kg) |
|---|---|---|---|---|---|
| $A_{01}$ | 850 | $C_{01}$ | 890 | $E_{01}$ | 950 |
| $A_{02}$ | 967 | $C_{02}$ | 798 | $E_{02}$ | 1,010 |
| $A_{03}$ | 820 | $C_{03}$ | 720 | $E_{03}$ | 978 |
| $A_{04}$ | 898 | $C_{04}$ | 705 | $E_{04}$ | 810 |
| $B_{01}$ | 770 | $D_{01}$ | 989 | $F_{01}$ | 720 |
| $B_{02}$ | 730 | $D_{02}$ | 996 | $F_{02}$ | 725 |
| $B_{03}$ | 820 | $D_{03}$ | 810 | $F_{03}$ | 700 |
| $B_{04}$ | 1,050 | $D_{04}$ | 987 | $F_{04}$ | 996 |

**Table 8. Harvest comparison**

| Total Harvest Comparison | Unit | Existing Condition | Prediction |
|---|---|---|---|
| Harvest Production | t | 44,615 | 0.862 |
| Area | ha | 2,895 | 0.063 |
| Productivity | t ha-1 | 15.41 | 13.79 |

**Table 9. Prediction of potato production of industrial raw materials**

| Code | Location | Latitude | Longitude | Existing production (t) | Prediction (t) |
|---|---|---|---|---|---|
| $P_1$ | Kejajar | 7°14′11.8″S | 109°56′29.7″E | 67,059 | 59,917 |
| $P_2$ | Garung | 7°16′52.1″S | 109°56′37.2″E | 11,136 | 9,950 |
| $P_3$ | Mojotengah | 7°17′31.6″S | 109°52′31.7″E | 136 | 121 |
| $P_5$ | Kalikajar | 7°22′38.5″S | 109°59′33.6″E | 2,952 | 2,638 |
| | Total | | | 81,438 | 72,765 |

**Table 10. The scenario of an alternative strategy**

| Scenario | Description | Percentage (%) | Production (t) | Total (t) |
|---|---|---|---|---|
| | Production shortage | 100 | | 44,235 |
| 1 | Increase production | 30 | 21,829 | |
| 2 | Fulfill from another region | 31 | 22,406 | |
| Total | | | 44,235 | 44,235 |

The predicted total industrial potato production from four sub-districts with suitable cropland sustainability is 72,765 t year$^{-1}$. Based on the demand for raw materials for industrial potatoes in Central Java of 117,000 t, there is a production shortage of 44,235 t (37.81%).

The first alternative strategy is to increase production by 61% to 117,151 tons in five potato-producing sub-districts in Kejajar, Garung, Mojotengah, and Kalikajar. The second scenario meets the production shortage of 44,235 t from other regions (Banjarnegara and Brebes District, Indonesia) to balance supply and demand. Based on Kementan (2015), the maximum ability to increase the production of agro-industrial commodities for normal conditions is 30%, so the recommendation of this model is to increase production by 30% in 5 potato-producing districts by 21,829 t (first scenario) and fulfill from other regions by 31%, namely 22,406 t (second scenario).

The total demand ($Q_d$) is 42,170 t month$^{-1}$ or 506,040 t year$^{-1}$. The prioritized supplier is $P^1$ (Kejajar), with a supply capacity ($Q_s$) of 399,448 t year$^{-1}$, so it is necessary to meet supply shortages. The concept of a logistics transparency approach is to know the amount of demand at one point and the supply capacity at another. A more analytical balance is obtained by increasing the supply from $P_2$ (Garung) 66,333 t, $P_3$ (Mojotengah) 809 t, and $P_5$ (Kalikajar) 17,587 t. This research has succeeded in showing the level of accuracy at the application level. The spatial-based logistics transparency approach can predict food availability, affordability, and utilization compared to the actual condition with a balanced level of 485,098 tons or 95.86%.

## 4. CONCLUSION

The results showed that the most suitable agricultural land was 11.05%; according to 22.9%, land with several inhibiting factors was 62.01%. The most convenient location is in Kejajar, Wonosobo District, Indonesia. The results also showed an average harvest of 13.79 t ha$^{-1}$. This model can predict the amount of crop with a production prediction of 72,765 t year$^{-1}$ and an accuracy rate of 89.35%. This study's results align with Kumar & Bhardwaj, who stated that predicting the total harvest using a modified model produces better accuracy (Bhardwaj & Kumar, 2022). The results of this study also strengthen the opinions of Jayasinghe & Withanage, which state that GIS

can provide better spatial data and visual data representation to improve prediction accuracy (Jayasinghe & Withanage, 2020).

This study succeeded in predicting a total production of 72,765 t year$^{-1}$. There needed to be more industrial potato production of 44,235 t (37.81%). So, the recommendation from this model is an increase in output by 30% in 5 potato-producing districts in Wonosobo, Central Java, by 21,829 t (first scenario) and fulfillment from other regions by 31%, namely 22,406 t (second scenario), to balance supply and demand. This study also managed to show the level of accuracy at the application level. A spatial-based logistics transparency approach can predict food availability, affordability, and utilization compared to actual conditions with a balanced level of 485,098 t or 95.86%. It shows that an adaptive model can predict cropland suitability and total harvest.

## CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest.

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors.

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# EVALUATION OF CONVENTIONAL AND ZERO TILLAGE FOR POTATO CULTIVATION IN RICE – POTATO SEQUENCE

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**ABSTRACT: A field study was conducted at the research farm of ICAR-Central Potato Research Institute RS, Gwalior (M.P.) during *Rabi* 2020-21 with three levels of rice cuttings *viz*. ground level, at 30 cm height and 60 cm height; and three tillage practices *viz*. tuber zone tillage, tuber row zone tillage and normal tillage, replicated thrice. Highest tuber emergence count (98.3%) was recorded with ground level rice harvest + tuber row zone tillage. Rice harvest at 60 cm height + tuber row zone tillage recorded highest plant height (41.3 cm). Highest fresh haulm weight/plant was recorded with rice harvest at 30 cm height + normal tillage (173.7 g). Highest tuber yield/plant was recorded with rice harvest at 30 cm height + normal tillage (144.9 g). Highest total number of tuber was recorded with ground level rice harvest + tuber row zone tillage (575.7 thousand/ha). Highest total yield of tuber was recorded with rice harvest at 30 cm height + normal tillage (16.5 t/ha) which was significantly higher than $T_3$ but statistically same with all other treatments. Highest net return was recorded with rice harvest at 30 cm height + normal tillage (27.3 thousand/ha). Highest number (31.3%) and yield (28.9%) of green tuber was recorded with rice harvest at 30 cm height + tuber zone tillage. Overall, integrated management of soil including conservation tillage is essential to enhance the crop productivity, economic profitability, and environmental quality.**

**KEYWORDS:** Tuber zone tillage, tuber row zone tillage, normal tillage, Potato

## INTRODUCTION

Potato (*Solanum tuberosum* L.) is worldwide grown and is very sensitive to soil and water conditions as it grows and produces better on deep and well-drained soils (Djaman *et al*., 2021). Potato is the 4$^{th}$ largest crop produced worldwide after rice, wheat, and maize (FAOSTAT, 2021). Tillage at different planting and growth stages of potatoes is a requirement and necessary for preparing a seedbed and for weed control. Potato production is associated with different practices such as planting, diking, cultivation, hilling, and harvest that significantly disturb the soil environment with heavy machinery. Soil and water management in potatoes are therefore critical to assure optimal crop growth and development. Tillage practices are adopted to create the proper environment for potato growth and yield potential. Commercial potato production under traditional management practices involves heavy to very heavy machinery and equipment during seedbed preparation and during the growing season for different operations such as cultivation, herbicide and pesticides application and harvest, exposing the soil to compaction (Paul *et al.,* 2016; Choudhary *et al.,* 2010, 2021). Compaction before and during planting can restrict root growth (Rajpoot *et al*., 2021). Huntenburg *et al.* (2021) also found that potato shoot growth was restricted by adverse compacted soil conditions. Soil compaction in combination with drought can decrease plant water availability and limit biomass production and potato tuber dry weight (Huntenburg

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*et al*., 2021). Larney *et al*. (2016) reported that integration of conservation management practices led to yield and disease control benefits without negatively impacting tuber quality. Conservation tillage practices increase soil organic matter of the topsoil and can improve soil structure and soil biological properties during the potato growing season within the rotation cropping systems (Carter and Sanderson, 2001; Kumar *et al.,* 2021). Deep soil tillage such as ploughing and ridging promote plant growth and macronutrient (N, P, K, Ca, and Mg) uptake by potato plant and translocation in potato tubers (Nunes *et al*., 2006). While potato growers usually opt for deep ploughing before seedbed preparation and ridging to ensure an adequate volume of loose-structured soil which is required for optimal tuber formation and quality, this intense soil preparation may be detrimental to soil structure, soil quality, and promote soil erosion (Drakopoulos *et al*., 2016). Potato (*Solanum tuberosum* L.) is an intensively managed crop with yields often limited by subsoil compaction and tillage pans and the mechanical loosening of compacted soil via subsoiling is often believed to be a useful method to enhance root elongation and improve a crop's ability to access deeper soil water (Ghosh and Daigh, 2020). Drakopoulos *et al*. (2018) investigated the effect of reduced tillage and standard tillage practices on soil quality indicators in organic potato production system and found that soil temperature and soil moisture content were not found to be greatly affected by tillage practices; soil mineral N ($NO_3$ and $NH_{4+}$) concentrations showed similar decreasing patterns over time across both tillage systems during the potato production period, however, soil mineral N was overall higher in the upper 15 cm soil layer under reduced tillage and in the 15–30 cm soil layer under standard tillage.

## MATERIALS AND METHODS

A field study was conducted at the research farm of ICAR-Central Potato Research Institute RS, Gwalior (MP) during the *Rabi* season of 2020- 21. Geographically, Gwalior is located at 26.22° North latitude and 78.18° East longitude and 197 meter above mean sea level which lies in the north tract of M.P. The climate of experimental site was semi-arid with extremely hot summers and cold winters. The soil was silty clay loam with pH 7.3. Potato cv. 'Kufri Chandramukhi' was grown with 9 treatment combinations. Treatments consisted of conservation tillage for potato cultivation *viz* T1: Ground level rice harvest + tuber zone tillage, T2: Ground level rice harvest + tuber row zone tillage, T3: Ground level rice harvest + normal tillage, T4: Rice harvest at 30 cm height + tuber zone tillage, T5: Rice harvest at 30 cm height + tuber row zone tillage, T6: Rice harvest at 30 cm height + normal tillage, T7: Rice harvest at 60 cm height + tuber zone tillage, T8: Rice harvest at 60 cm height + tuber row zone tillage, T9: Rice harvest at 60 cm height + normal tillage. Treatments were replicated thrice. Direct seeded rice was sown on raised beds of 120 cm width. Crop was fertilized with 120 kg N, 40 kg $P_2O_5$ and 20 kg $K_2O$/ha. Potato tubers were planted just after harvest of rice as per treatment. Recommended dose of nutrients, *i.e.* 180:80:120 kg/ha of N:$P_2O_5$:$K_2O$, respectively were applied as per schedule during crop raising. Half N and full quantity of $P_2O_5$ and $K_2O$ were applied before planting and remaining half N dose was applied at earthing up. Gross plot size was 3.6 m × 4.0 m. Well sprouted potato tubers were planted on 25.11.2020. Four irrigations were applied as per requirement in addition to winter rains on 4.12.2020, 29.12.2020, 14.1.2021 and 15.2.2021. Crop was sprayed with herbicide metribuzin @ 0.5 kg a.i./ha on 26.11.2020 for control of weeds. For control of

insect's insecticide imidacloprid was sprayed @ 4 ml/10 liter water on 14.12.2020. Haulm killing of potato was done at 90 days after planting (physiological maturity) on 25.2.2021 to facilitate timely harvesting. Crop was harvested after haulm killing on 5.3.2021 to estimate fresh tuber yield. To assess economic viability of different treatments for potato production, both fixed and operating costs were taken into consideration. Economics of potato production under variable treatments were calculated (Rana *et al*., 2014). Net returns were estimated as difference between gross income and total production cost. Gross returns were product of yield and wholesale market price of potato. The experiment was laid out in completely randomized block design (CRBD). The data were analyzed statistically by standard analysis of variance (ANOVA). Least significant difference (LSD) test was used to determine whether differences exist between certain comparisons. The probability level for determination of significance was 0.05.

## RESULTS AND DISCUSSION

### Emergence count

Highest emergence count was recorded with T2: Ground level rice harvest + tuber row zone tillage (98.3%) which was significantly higher than T5, T6 and T8 but statistically same with T1, T3, T4, T7 and T9. Number of compound leaves and number of stems/plant were statistically not influenced by different treatments. T8: Rice harvest at 60 cm height + tuber row zone tillage recorded highest plant height (41.3 cm) which was significantly higher than all other treatments except T1. Highest fresh haulm weight/ plant was recorded with T6: Rice harvest at 30 cm height + normal tillage (173.7 g) which was significantly higher than all other treatments except T5, T8 and T9.Yaroson *et al.* (2019) investigated potato response to ridges tillage, zero-tillage, mound tillage, and flat tillage in Nigeria and found that soil management practices had a significant effect on plant height, the number of leaves, leaf area, canopy cover, and tuber yield. Highest tuber number/plant was recorded with T5: Rice harvest at 30 cm height + tuber row zone tillage which was significantly higher than all other treatments except T2. Highest tuber yield/plant was recorded with T6: Rice harvest at 30 cm height + normal tillage (144.9 g) which was significantly higher than all other treatments except T1 and T2. Nelson and Giles (2017) found that multiple cultivations provided better weed control in potatoes than the herbicide pendimethalin alone but not as good as pendimethalin and cultivation combined. Highest fresh haulm yield/ha was recorded with T9: Rice harvest at 60 cm height + normal tillage (6.4 t) which was significantly higher than all other treatments except T6 and T8. Dry haulm yield/ha was statistically same under all the treatments.

### Number and yield of tubers

Number of <25g tubers ('000/ha) were statistically same under all the treatments. Highest number of 25-50 g tuber was recorded with T3: Ground level rice harvest + normal tillage (158.7 thousand/ha) which was significantly higher than T4,T7 and T8 but statistically same with all other treatments.Number of 50-75g tubers ('000/ ha) were highest in T6: Rice harvest at 30 cm height + normal tillage which were statistically same under all the treatments. Highest number of >75 g tuber was recorded with T9: Rice harvest at 60 cm height + normal tillage (46.0 thousand/ha) which was significantly higher than T7 but statistically same with all other treatments. Highest total number of tuber was recorded with T2: Ground level rice harvest + tuber row zone tillage (575.7 thousand/ha) which was

significantly higher than T7, T8 and T0 but statistically same with all other treatments (Table 1).

Yield of <25g tubers (3.8 t/ha) was highest withT4: Rice harvest at 30 cm height + tuber zone tillage which was significantly higher than T9 but statistically same under all other treatments. Highest yield of 25-50 g tuber was recorded with T3: Ground level rice harvest + normal tillage (5.5 t/ha) which was significantly higher than T6 and T9 but statistically same with all other treatments. Yield of 50-75g tubers (5.5 t/ha) was recorded with T6: Rice harvest at 30 cm height + normal tillage which was significantly higher than T4,T5,T7,T8,T9 but statistically same under all other treatments. Highest yield of >75 g tuber was recorded with T9: Rice harvest at 60 cm height + normal tillage (3.6 t/ha) which was significantly higher than all other treatments but statistically same with T6. Drakopoulos *et al.* (2016) compared reduced tillage to standard tillage and found a decrease in tuber yield by 13.4 % under reduced tillage compared to standard tillage due to lower average tuber size which was related to higher soil bulk density and increased vulnerability to drought stress during tuber bulking. Highest total yield of tuber was recorded with T6: Rice harvest at 30 cm height + normal tillage (16.5 t/ha) which was significantly higher than T3 but statistically same with all other treatments. Reduced tillage showed the highest yield followed by mound tillage, flat tillage, and zero tillage with the lowest tuber yield (Yaroson *et al.*, 2019).

Highest dry yield of tuber was recorded with T6: Rice harvest at 30 cm height + normal tillage (3.8 t/ha) which was significantly higher than all other treatments except T3 (Table 2). Ghosh and Daigh (2020) concluded that potato yield and quality benefits from subsoiling are rare, temporary, and highly inconsistent and pointed that the only exception is when moisture is known to be the major limiting factor in a field.

**Table 1. Effect of minimum tillage on growth and yield attributes of potato in rice - potato sequence.**

| Treatments | Tuber emergence (%) | Compound leaves/ plant | Stem/ plant | Plant height (cm) | Fresh haulm weight/ plant (g) | Tuber number /plant | Tuber yield/ plant (g) | Fresh haulm yield (t/ha) | Dry haulm yield (t/ha) | Number of tuber ('000/ha) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | <25 g | 25-50 g | 50-75 g | >75g | Total |
| T1 | 97.5 | 50.6 | 3.9 | 39.8 | 122.7 | 7.7 | 138.8 | 4.0 | 0.7 | 329.2 | 105.9 | 85.9 | 38.2 | 559.2 |
| T2 | 98.3 | 44.1 | 3.7 | 33.5 | 105.4 | 10.9 | 125.3 | 5.0 | 0.7 | 294.2 | 151.8 | 88.8 | 40.9 | 575.7 |
| T3 | 96.4 | 41.1 | 2.9 | 33.9 | 115.0 | 7.1 | 111.2 | 4.0 | 0.6 | 288.4 | 158.7 | 86.4 | 39.9 | 573.3 |
| T4 | 96.7 | 42.6 | 3.6 | 30.8 | 94.2 | 9.4 | 93.3 | 5.2 | 0.8 | 304.2 | 102.4 | 81.5 | 31.6 | 519.8 |
| T5 | 94.4 | 44.4 | 3.1 | 35.4 | 151.6 | 11.6 | 120.4 | 5.3 | 0.7 | 312.4 | 128.2 | 76.4 | 45.0 | 562.1 |
| T6 | 94.2 | 48.1 | 3.6 | 33.1 | 173.7 | 8.1 | 144.9 | 6.1 | 0.7 | 256.2 | 113.2 | 95.6 | 41.4 | 506.4 |
| T7 | 95.6 | 40.1 | 3.1 | 37.0 | 127.3 | 7.9 | 105.8 | 4.5 | 0.6 | 303.2 | 86.1 | 38.4 | 20.9 | 448.7 |
| T8 | 93.1 | 37.3 | 3.3 | 41.3 | 163.1 | 9.4 | 98.4 | 5.4 | 0.6 | 224.8 | 65.0 | 46.5 | 28.2 | 364.5 |
| T9 | 97.2 | 38.7 | 2.7 | 31.7 | 142.4 | 9.1 | 116.3 | 6.4 | 0.8 | 203.4 | 117.5 | 54.0 | 46.0 | 421.0 |
| SEm± | 1.0 | 2.8 | 0.4 | 1.3 | 11.8 | 0.5 | 7.7 | 0.4 | 0.1 | 31.1 | 16.3 | 19.3 | 5.1 | 36.2 |
| CD (*P*=0.05) | 3.0 | NS | NS | 3.9 | 35.7 | 1.6 | 23.2 | 1.1 | NS | NS | 49.3 | NS | 15.3 | 109.3 |

T1: Ground level rice harvest + tuber zone tillage, T2: Ground level rice harvest + tuber row zone tillage, T3: Ground level rice harvest + normal tillage, T4: Rice harvest at 30 cm height + tuber zone tillage, T5: Rice harvest at 30 cm height + tuber row zone tillage, T6: Rice harvest at 30 cm height + normal tillage, T7: Rice harvest at 60 cm height + tuber zone tillage, T8: Rice harvest at 60 cm height + tuber row zone tillage, T9: Rice harvest at 60 cm height + normal tillage

**Table 2. Effect of minimum tillage on yield and economics of potato in rice-potato sequence.**

| Treatments | Yield of tubers (t/ha) | | | | | | Economics of potato cultivation ('×000 ₹/ha) | | | | Haulm dry matter (%) | Tuber dry matter (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | <25 | 25-50 | 50-75 | >75g | Total | Dry tuber | Cost of cultivation | Gross Return | Net Return | B : C | | |
| T1 | 3.2 | 3.8 | 4.8 | 2.2 | 14.0 | 3.1 | 125.4 | 139.6 | 14.2 | 1.1 | 17.3 | 23.5 |
| T2 | 3.6 | 3.6 | 4.7 | 2.5 | 14.3 | 3.3 | 125.9 | 143.4 | 17.5 | 1.1 | 13.7 | 23.3 |
| T3 | 3.3 | 5.5 | 5.2 | 2.3 | 16.2 | 3.7 | 137.4 | 161.8 | 24.4 | 1.2 | 15.1 | 22.7 |
| T4 | 3.8 | 3.6 | 4.6 | 2.0 | 14.1 | 3.2 | 125.4 | 141.3 | 15.9 | 1.1 | 14.5 | 22.9 |
| T5 | 3.5 | 3.7 | 3.8 | 2.5 | 13.6 | 3.1 | 125.9 | 135.5 | 9.6 | 1.1 | 13.3 | 24.4 |
| T6 | 3.0 | 4.8 | 5.5 | 3.2 | 16.5 | 3.8 | 137.4 | 164.7 | 27.3 | 1.2 | 12.1 | 23.1 |
| T7 | 3.5 | 2.7 | 2.4 | 1.1 | 9.6 | 2.0 | 125.4 | 95.8 | -29.6 | 0.8 | 14.0 | 20.9 |
| T8 | 1.9 | 1.7 | 2.3 | 1.0 | 6.9 | 1.5 | 125.9 | 69.0 | -57.0 | 0.5 | 11.1 | 23.4 |
| T9 | 2.5 | 4.4 | 3.2 | 3.6 | 13.7 | 2.8 | 137.4 | 136.9 | -0.5 | 1.0 | 12.5 | 20.6 |
| SEm± | 0.4 | 0.4 | 0.3 | 0.4 | 0.5 | 0.2 | 0 | 5.1 | 5.1 | 0.0 | 1.3 | 1.0 |
| CD (*P*=0.05) | 1.1 | 1.1 | 0.9 | 1.1 | 1.6 | 0.5 | 0 | 15.5 | 15.5 | 0.1 | NS | NS |

## Economic parameters

T3: Ground level rice harvest + normal tillage recorded highest cost of cultivation 137.4 thousand/ha which was same with T6 and T9 but higher than all other treatments. Highest gross return was recorded with T6 (164.7 thousand/ha) which was significantly higher than all other treatments except T3. Highest net return was recorded with T6 (27.3 thousand/ha) which was significantly higher than T5, T7, T8 and T9 but statistically on par with all other treatments. Highest benefit cost ratio was recorded with T6 (1.2) which was significantly higher than all other treatments except T3. Larney *et al*. (2016) in a 12-year study compared conservation and conventional management for potato in 3- to 6-year rotations which also included dry bean, sugar beet, and soft wheat, oat and timothy, and showed that the conservation management resulted in 18% higher marketable tuber yield and reduced early dying than conventional management under a short term rotation. Haulm dry matter content ranged from 11.1 to 17.3% but values were statistically same under different treatments. Tuber dry matter % ranged from 20.6 to 24.4 but values were statistically same under different treatments (Table 2).

## Number of tubers under different categories

Number of normal tubers (486.8 thousand/ha) were recorded with T3 which was significantly higher than all other treatments except T2 and T6. Highest number of green tuber was recorded with T4 (162.5 thousand/ha) which was significantly higher than T3, T6 and T9 but statistically same with all other treatments. Highest number of cut tuber was recorded with T3 (27.8 thousand/ha) which was statistically same with all other treatments. Highest number of green tuber was recorded with T4 (31.3%) which was significantly higher than T3 and T6 but statistically same with all other treatments. Highest number of cut tuber was recorded with T8 (7.9%) which was statistically same with all other treatments (Table 3).

## Yield of tubers under different categories

Highest yield of normal tubers (14.2 t/ha) was recorded with T6 which was significantly higher than T3 but statistically same with all

**Table 3. Effect of minimum tillage on production of different categories of potato tubers in rice-potato sequence.**

| Treatments | Number of tuber (×000/ha) | | | | | | Yield of tuber (t/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Normal | Green | Cut | Total | Green (%) | Cut (%) | Normal | Green | Cut | Total | Green (%) | Cut (%) |
| T1 | 393.8 | 141.3 | 24.9 | 559.9 | 25.7 | 4.5 | 9.6 | 3.5 | 0.9 | 14.0 | 25.3 | 6.8 |
| T2 | 416.9 | 136.5 | 23.1 | 576.5 | 23.6 | 4.0 | 10.7 | 2.9 | 0.7 | 14.4 | 20.3 | 4.8 |
| T3 | 486.8 | 59.5 | 27.8 | 574.1 | 10.1 | 4.9 | 13.8 | 1.5 | 1.0 | 16.2 | 9.2 | 5.8 |
| T4 | 336.0 | 162.5 | 21.9 | 520.5 | 31.3 | 4.3 | 9.2 | 4.1 | 0.9 | 14.1 | 28.9 | 6.5 |
| T5 | 382.6 | 158.6 | 21.7 | 562.9 | 28.1 | 3.9 | 9.6 | 3.3 | 0.7 | 13.6 | 24.0 | 5.0 |
| T6 | 424.5 | 64.3 | 18.3 | 507.1 | 12.4 | 3.5 | 14.2 | 1.7 | 0.6 | 16.5 | 10.0 | 3.9 |
| T7 | 309.2 | 123.8 | 16.3 | 449.3 | 27.5 | 3.6 | 6.6 | 2.4 | 0.5 | 9.6 | 25.0 | 5.4 |
| T8 | 234.9 | 105.0 | 25.1 | 365.0 | 28.0 | 7.9 | 4.5 | 1.7 | 0.7 | 6.9 | 24.8 | 10.5 |
| T9 | 315.5 | 84.6 | 21.4 | 421.5 | 20.2 | 5.1 | 11.1 | 1.7 | 0.9 | 13.7 | 12.4 | 6.5 |
| SEm± | 30.1 | 23.3 | 3.8 | 36.2 | 3.8 | 1.2 | 0.8 | 0.5 | 0.1 | 1.0 | 3.3 | 1.1 |
| CD (*P*=0.05) | 91.0 | 70.3 | NS | 109.5 | 11.6 | NS | 2.5 | 1.5 | NS | 3.0 | 9.9 | 3.4 |

other treatments. Eddis *et al.* (2020) found a significant positive correlation between high compaction and the high proportion of small size potato tubers in Saudi Arabia and a significant negative correlation between high compaction and the high proportion of large size tubers. Highest yield of green tuber was recorded with T4 (4.1 t/ha) which was significantly higher than T3, T6, T8 and T9 but statistically same with all other treatments. Highest yield of cut tuber was recorded with T3 (1.0 t/ha) which was statistically same with all other treatments. Highest yield of green tuber was recorded with T4 (28.9%) which was significantly higher than T3, T6 and T9 but statistically same with all other treatments. Highest yield of cut tuber was recorded with T8 (10.5%) which was statistically same with all other treatments (Table 3). Potato tuber quality in terms of crude protein, fat, crude fiber, and carbohydrate was better under zero tillage planting with paddy straw mulching compared to ridge planting (Sangari *et al.*, 2021; Larkin *et al.*, 2021).

## CONCLUSION

Commercial potato growers are more favorable to intensive tillage practices but the machinery traffic across the field may result in deep soil compaction incompatible with potato root growth, maximum tuber yield and grade. Therefore, potato producers should be aware of the contrasting results however, they should adopt integrated management of soil and potato crop contributing to the improvement of soil health including cover cropping, crop rotations, soil amendments, and conservation tillage that may enhance crop productivity, system sustainability, system vitality, economic profitability, and environmental quality.

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# KUFRI KIRAN: A NEW HEAT TOLERANT POTATO VARIETY

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**ABSTRACT: Kufri Kiran is a heat tolerant table potato variety suitable for early planting in North Indian plains and for main season planting in plateau regions. It is a clonal selection from the cross CP2372 × CP1748. Its plants are medium tall and vigorous with tolerance to mite and hopperburn. It produces attractive white-cream, ovoid tubers with shallow eyes and cream flesh, possesses 19% tuber dry matter and has excellent keeping quality. Kufri Kiran has the ability to produce up to 11% higher tuber yield than heat tolerant varieties Kufri Lima and Kufri Surya in North Indian plains in 15-20 days early planted crop.**

**KEYWORDS:** Kufri Kiran, heat tolerance, mite and hopper burn, early planting.

## INTRODUCTION

Potato (*Solanum tuberosum* L.) crop grows best in cool but frost-free areas and seasons throughout the world and does not perform well in heat due to photo and thermo-sensitivity of the crop (Minhas *et al*. 2011; Hijmans 2003). The yield and quality of potatoes are very sensitive to high temperatures (Bodlaender 1963; Ewing 1981). At high temperatures (above 17$^0$C) tuberisation diminishes (Reynolds & Ewing, 1989). High temperatures delay, impede or even inhibit tuber initiation (Minhas *et al*., 2006). Potato tuber initiation and development are much more sensitive to high-temperature stress than photosynthesis (Reynolds & Ewing, 1989). High night temperatures are much more deleterious to the formation of tubers than day temperatures. Minimum night temperature is very important for potato crops; whether or not potatoes will tuberise depends largely on the minimum night temperature and not on the average daily temperature. Night temperatures above 20$^o$C severely depress both tuber initiation and bulking and temperatures above 25$^o$C effectively stop tuber production (Minhas *et al*., 2001). Optimum temperatures for tuber formation are widely regarded as 10-17°C (Bodlaender 1963; Moorby and Milthorpe 1975). India has set a target to produce 125 million tonnes of potatoes to meet future requirements by 2050 (Singh et.al., 2014). These increased production targets can be met from the increased area (from sandwiched early crops of northern plains, the plateau and other non-traditional warmer areas including coastal areas) (Gupta *et al*, 2020 and Gupta *et al*, 2020a), productivity and improved mitigation strategies for various potato production agro-ecologies. In India, the effect of high temperatures not only affects the early-season crop of the north-western

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plains but it also affects the main-season crop of the central and eastern plains. Such heat stress conditions either affect the initial growth stages during the tuber formation stage or at a later stage (harvest). Transitory or constant high temperatures have a number of morpho-anatomical, physiological and biochemical changes in plants, which affect plant growth, development and potato crop may get infestation with a number of insect pests especially leaf hoppers and mites which may lead to a drastic reduction in economic yield (Wahid *et al*. 2007, Malik and Luthra 2007, Sunitha *et al*. 2020, Rao *et al*. 2018, Luthra *et al*. 2013). To overcome or reduce the impact of such abiotic stresses, potato genotypes with better sustenance may help to fulfil future production targets. ICAR-CPRI has developed the first heat-tolerant variety Kufri Surya (Minhas *et al*. 2006). A new heat-tolerant variety Kufri Kiran has been developed which would provide another alternative to extend potato cultivation in non-traditional and warmer areas besides the early crop (15-20 days earlier than the main season crop) of vast northern plains.

## MATERIALS AND METHODS

**Evaluation and testing of advanced clone:** Advanced stage clone HT/07-1329 named Kufri Kiran originated from hybridization of cross CP2372 x CP1748 attempted in 2007 at Kufri (31° 1′N 77° 3′E; 2501 m above MSL) in the mid-hills of Himachal Pradesh. Seedlings and subsequent clonal generations were raised and evaluated at the ICAR-Central Potato Research Institute (CPRI), Regional Station, Modipuram, Meerut, UP (29° 4′ N and 77° 46′ E; 237m above msl) as per procedure described by Luthra (2020). The pedigree of Kufri Kiran has been described in **Fig. 1**. The female parent CP2372 (LT-9 a CIP advanced clone of low land tropic group) produces

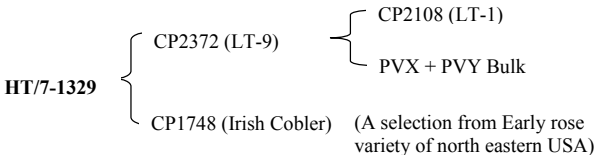



*Fig. 1. Pedigree of Kufri Kiran*

white-cream ovoid, shallow eyed tubers with cream flesh and possesses tolerance to heat, whereas the male parent CP1748 an exotic variety Irish Cobler produces white-cream ovoid tubers with shallow eyes and cream flesh.

The clone HT/07-1329 was in the seedling stage in 2007-08, the five-hill plot in 2008-09, 30 hill plot in 2009-10, multiple-row trial in 2010-11, in replicated yield trials at Modipuram during 2012-15, and at Pune, Maharashtra and Ladol (Gujarat) during 2014-15 and 2015-16. Based on its superior performance over control varieties in yield trials, HT/07-1329 was introduced in AICRP in the year 2016 for multi-location testing across the country. This advanced clone was evaluated during 2018-20 at 11 locations in three regions i.e., north-western (3 locations at Hisar, Jalandhar and Pantnagar), central (5 locations at Chhindwara, Deesa, Gwalior, Kanpur and Raipur) and eastern plains (3 locations at Bhubaneshwar, Faizabad and Kalyani) in multi-location replicated, initial and advanced varietal trails under AICRP.

The data were analyzed following standard statistical procedures as described by Gomez and Gomez (1984) using the software Windostat 8.5 (Ameerpet, Hyderabad, India). Based on its performance over the years/ locations, the advanced clone HT/07-1329 has been recommended for release in the 38th group meeting of AICRP (Potato) held during 28-30 September 2020 through virtual mode. Subsequently, advanced clone HT/07-1329 was released and notified as variety in the name of Kufri Kiran by the Central Sub-

Committee on Crop Standards Notification and Release of Varieties for Horticultural Crops, Ministry of Agriculture, Department of Agriculture and Co-operation, Government of India, New Delhi vide Gazette Notification S.O.No. 692(E); dated 05.02.2019.

## VARIETAL DESCRIPTION

***Plant:*** Medium, canopy semi-compact, stem medium thick, predominantly green with secondary colouration red brown lightly scattered throughout, wings highly developed and straight.

***Foliage:*** Grey green, leaves intermediate, leaf width medium, leaflets ovate-lanceolate, leaflet coalescence absent, rachis green, midrib green.

***Flowering:*** Medium (**Fig. 2**), inflorescence small, floral stalk green, floral stalk-pedicle articulation clearly visible and located above the middle, calyx green, corolla light purple white, corolla shape pentagonal, anther yellow, anther cone normally developed, stylar length longer with stamen column and stigma bi-lobed

***Tubers:*** Medium 7-8 tuber per plant, ovoid (**Fig.2**). *skin*-smooth, white-cream, *eyes-shallow*,, *flesh*- cream-texture mealy.

***Sprout:*** Red purple, shape spherical, pubescence at sprout base weak.

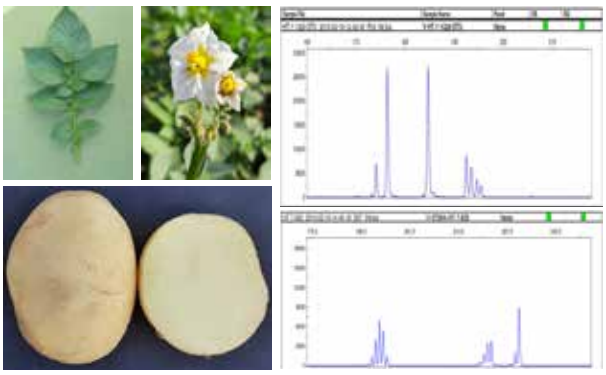


*Fig. 2. Morphological features and DNA fingerprint profile of Kufri Kiran*

**DNA fingerprinting:** The fingerprint of clone, HT/07-1329 was generated using 2 SSR markers viz., STU and STIKA using a genetic analyzer, ABI 3500. The fingerprints are clearly unique and do not match any of the existing indigenous varieties (**Fig 2**).

## YIELD PERFORMANCE

***Primary evaluation trials:*** At Modipuram (UP) during 2014 and 2015), HT/07-1329 produced a 6% higher total tuber (13 t/ha) yield over the best control Kufri Surya (12 t/ha) at 75 days in early crop of the winter season (**Table 1**). At Pune (Maharashtra), HT/07-1329 produced a 12 % higher total tuber yield (17 t/ha) over the best control Kufri Surya (15 t/ha) at 90 days in the Kharif season crop **(Table 2)**. At Ladol (Gujarat), HT/07-1329 produced 23% higher total tuber yield (55 t/ha) over the best control Kufri Surya (45 t/ha) at 90 days early crop **(Table 3)**.

***Multi-location testing:*** Under AICRP, the advanced stage clone HT/07-1329 performed well as compared to control varieties in

**Table.1: Performance and attributes of HT/07-1329 during 2014 and 2015 at Modipuram**

| Genotypes | Total Tuber Yield (t/ha) | | Mean | Dry matter (%) | | Mean |
|---|---|---|---|---|---|---|
| | 2014 | 2015 | | 2014 | 2015 | |
| HT/07-1329 | 9.8 | 15.5 | 12.7 | 20.5 | 20.3 | 20.4 |
| Kufri Lauvkar | 7.8 | 12.7 | 10.3 | - | 17.1 | 17.1 |
| Kufri Surya | 8.3 | 15.6 | 11.9 | 19.2 | 19.1 | 19.1 |
| C.D. 5% | 1.33 | 2.18 | | | 0.68 | |

**Table.2: Performance and attributes of HT/07-1329 during 2014 and 2015 at Pune**

| Genotypes | Total Tuber Yield (t/ ha) | | Mean |
|---|---|---|---|
| | 2014 | 2015 | |
| HT/07-1329 | 18.33 | 15.67 | 17.0 |
| Kufri Surya | 19.16 | 11.24 | 15.2 |
| Kufri Jyoti | - | 13.80 | 13.8 |
| C.D. 5% | 1.39 | 0.96 | |

**Table.3: Performance and attributes of HT/07-1329 during 2014-15 and 2015-16 at Ladol**

| Genotypes | Marketable Tuber Yield (t/ha) | | Mean | Total Tuber Yield (t/ha) | | Mean |
|---|---|---|---|---|---|---|
| | 2014-15 | 2015-16 | | 2014-15 | 2015-16 | |
| HT/07-1329 | 41.4 | 66.6 | 54.0 | 42.3 | 68.1 | 55.2 |
| Kufri Surya | 31.5 | 55.9 | 43.7 | 31.9 | 57.9 | 44.7 |
| C.D. 5% | 2.39 | 4.32 | | 2.76 | 4.29 | |

replicated trials during 2018-19 and 2019-20 at 11 locations of Northern, Central and Eastern plains. Pooled results of the advanced clone with superior performance are summarized as under-

**Total tuber yield (75 days):** HT/07-1329 produced significantly higher or at par total tuber yield than best control Kufri Lima at Hisar, Jalandhar, Pantnagar, Chhindwara, Deesa, Gwalior, Kanpur, Bhubaneswar, Faizabad and Kalyani **(Table 4).** However, at Raipur Kufri Surya outperformed control varieties. The mean total tuber yield of HT/07-1329 (29 t/ha) over different locations of northern, central and eastern plains was significantly higher than the best control Kufri Lima (27 t/ha) and with a yield advantage of 10%. HT/07-1329 has acceptable tuber dry matter content (18%) and 48 % foliage maturity **(Table 6, 7).**

**Marketable tuber yield (75 days):** HT/07-1329 also produced significantly higher or at par Marketable tuber yield than best control Kufri Lima at Hisar, Jalandhar, Pantnagar, Chhindwara, Deesa, Gwalior, Kanpur, Raipur, Bhubaneswar, Faizabad and Kalyani **(Table 4).** The mean Marketable tuber yield of HT/07-1329 (26 t/ha) over different locations of northern plains, central plains and eastern plains was significantly higher than the best control Kufri Lima (24 t/ha) and with yield advantage of 10%.

**Total tuber yield (90 days):** HT/07-1329 produced significantly higher or at par total tuber yield than control varieties at Hisar, Jalandhar, Pantnagar, Chhindwara, Deesa, Gwalior, Kanpur, Raipur and Faizabad (**Table 5).** The mean total tuber yield of HT/07-1329 (37 t/ha) over different locations of northern,

**Table.4 Tuber yield of HT/07-1329 (pooled mean of 2018-19 and2019-20) at 75 days**

| Regions | | Total tuber yield (t/ha) | | | Marketable tuber yield (t/ha) | | |
|---|---|---|---|---|---|---|---|
| | Locations | HT/07-1329 | Kufri Lima | Kufri Surya | HT/07-1329 | Kufri Lima | Kufri Surya |
| Northern plains | Hissar | 35.2 | 32.2 | 30.8 | 33.6 | 31.3 | 29.0 |
| | Jalandhar | 32.8 | 29.5 | 31.6 | 31.8 | 28.5 | 30.3 |
| | Pantnagar | 23.4 | 20.2 | 21.5 | 21.9 | 19.3 | 18.9 |
| Central plains | Chhindwara | 31.8 | 29.3 | 30.9 | 29.8 | 27.5 | 29.0 |
| | Deesa | 43.7 | 38.9 | 34.9 | 41.8 | 35.6 | 32.9 |
| | Gwalior | 33.5 | 32.6 | 25.5 | 29.5 | 29.6 | 22.6 |
| | Kanpur | 35.4 | 32.6 | 31.6 | 28.0 | 26.6 | 26.5 |
| | Raipur | 21.3 | 21.8 | 24.2 | 13.5 | 13.2 | 10.4 |
| Eastern plains | Bhubaneswar | 11.7 | 9.3 | 13.2 | 10.0 | 7.1 | 11.8 |
| | Faizabad | 30.3 | 25.5 | 24.8 | 27.7 | 23.5 | 22.9 |
| | Kalyani | 23.3 | 20.4 | 20.7 | 21.7 | 19.8 | 19.2 |
| | Mean | 29.3 | 26.6 | 26.3 | 26.3 | 23.8 | 23.0 |
| % Yield increase | | | 10.2 | 11.3 | | 10.3 | 14.2 |
| C.D. | | Var: 0.8, Var × Location: 2.7 | | | Var : 0.7, Var × Location:1.9 | | |

central and eastern plains was significantly higher than the controls Kufri Lima (35 t/ ha), Kufri Surya (32 t/ha) and with yield advantage of 7%, 14% respectively.

**Marketable tuber yield (90 days):** HT/07-1329 also produced significantly higher or at par Marketable tuber yield than control varieties at Hisar, Jalandhar, Pantnagar, Chhindwara, Deesa, Gwalior, Kanpur, Raipur and Faizabad **(Table 5).** The mean Marketable tuber yield of HT/07-1329 (34 t/ha) over different locations of northern plains, central plains and eastern plains was significantly higher than the controls Kufri Lima (31 t/ha), Kufri Surya (29 t/ha) and with yield advantage of 7%, 16% respectively. HT/07-1329 has acceptable tuber dry matter content (20%) and 79 % foliage maturity **(Table 6, 7).**

**The additional trial at YSR Horticulture University:** The advanced stage clone HT/07-1329 was evaluated for four years during 2016-17 to 2019-20. HT/07-1329 produced higher (24 t/ha) total tuber yield than best control Kufri Lima (19 t/ha) and Kufri Surya

**Table. 5 Tuber yield of HT/07-1329 (pooled mean of 2018-19 -2019-20) at 90 days**

| Regions/ 90 days | | Total tuber yield (t/ha) | | | Marketable tuber yield (t/ha) | | |
|---|---|---|---|---|---|---|---|
| | Locations | HT/07-1329 | Kufri Lima | Kufri Surya | HT/07-1329 | Kufri Lima | Kufri Surya |
| Northern plains | Hissar | 45.8 | 40.7 | 36.6 | 44.4 | 39.9 | 35.1 |
| | Jalandhar | 30.6 | 30.3 | 28.1 | 29.5 | 29.3 | 27.2 |
| | Pantnagar | 23.6 | 20.0 | 21.7 | 21.1 | 18.5 | 19.8 |
| Central plains | Chhindwara | 42.0 | 35.0 | 36.5 | 38.9 | 32.3 | 33.7 |
| | Deesa | 48.4 | 48.3 | 42.8 | 47.7 | 47.4 | 40.9 |
| | Gwalior | 39.8 | 37.0 | 29.0 | 36.5 | 34.5 | 25.9 |
| | Kanpur | 43.6 | 43.1 | 39.6 | 36.0 | 37.6 | 33.2 |
| | Raipur | 23.8 | 25.0 | 26.3 | 16.2 | 13.2 | 17.9 |
| Eastern plains | Faizabad | 35.9 | 32.2 | 31.3 | 33.7 | 30.3 | 29.4 |
| | Mean | 37.0 | 34.6 | 32.4 | 33.8 | 31.4 | 29.2 |
| % Yield increase | | | 7.0 | 14.3 | | 7.4 | 15.6 |
| C.D. | | Var: 1.04, Var × Location:3.28 | | | Var: 1.03, Var × Location:3.25 | | |

**Table. 6 Tuber Dry matter content of HT/07-1329 (pooled mean of 2018-19 and 2019-20)**

| Region | Locations | 75 days | | | 90 days | | |
|---|---|---|---|---|---|---|---|
| | | HT/07-1329 | Kufri Lima | Kufri Surya | HT/07-1329 | Kufri Lima | Kufri Surya |
| Northern plains | Hissar | 15.9 | 16.2 | 15.9 | 17.5 | 18.4 | 18.4 |
| | Jalandhar | 17.7 | 17.7 | 17.4 | 17.6 | 17.5 | 17.3 |
| Central plains | Chhindwara | 18.2 | 18.2 | 18.3 | 19.3 | 19.3 | 19.3 |
| | Deesa | 17.3 | 18.5 | 18.0 | 20.2 | 22.2 | 19.2 |
| | Gwalior | 20.7 | 20.3 | 19.9 | 21.1 | 21.5 | 20.9 |
| | Kanpur | 15.3 | 12.0 | 15.1 | 20.5 | 19.3 | 20.2 |
| | Raipur | 19.3 | 19.2 | 19.3 | 21.0 | 19.4 | 20.5 |
| Eastern plains | Faizabad | 17.5 | 17.5 | 17.7 | 18.4 | 18.3 | 18.6 |
| | Mean | 17.7 | 17.4 | 17.7 | 19.5 | 19.5 | 19.3 |
| C.D. | | Var: 0.2, Var × Location: 0.56 | | | Var: 0.16, Var × Location:0.49 | | |

(17 t/ha) with yield advantage of 23% and 38 % respectively **(Table 8).**

**Performance HT/07-1329 in AICRP at 75 days (pooled over locations):** In northern plains, HT/07-1329 (31 t/ha and 29 t/ha) yielded 9 and 11% higher total and marketable tuber yield than the best control Kufri Surya (28 t/ha and 26 t/ha), respectively at 75 days crop duration **(Table 9).** HT/07-1329 has tuber dry matter content (17%)**.** In central plains: HT/07-1329 (33 t/ha and 29 t/ha) yielded 7 and 8% higher total and marketable tuber yields than the best control Kufri Lima (31 t/ha and 27 t/ha), respectively at 75 days crop duration. HT/07-1329 has acceptable tuber dry matter content (18%). In eastern plains: HT/07-1329 (22 t/ha and 20 t/ha) yielded 11 and 10% higher total and marketable tuber yields than the best control Kufri Surya (20 t/ha and 18 t/ha), respectively at 75 days crop duration**.** HT/07-1329 has acceptable tuber dry matter content (18%)**.** The performance of over regions reflected that HT/07-1329 (29 t/ha and 26 t/ha) yielded 11% higher total and

**Table. 7 Foliage senescence (%) of HT/07-1329 (pooled man of 2018-19 and 2019-20)**

| Region | Locations | 75 days | | | 90 days | | |
|---|---|---|---|---|---|---|---|
| | | HT/07-1329 | Kufri Lima | Kufri Surya | HT/07-1329 | Kufri Lima | Kufri Surya |
| Northern plains | Pantnagar | 75.2 | 72.0 | 68.7 | 77.0 | 67.0 | 74.0 |
| Central plains | Chhindwara | 73.5 | 72.9 | 72.3 | 84.5 | 83.5 | 82.9 |
| | Deesa | 48.1 | 31.3 | 50.6 | 73.5 | 67.5 | 78.0 |
| Eastern plains | Bhubaneswar | 25.5 | 4.8 | 27.1 | 80.8 | 80.0 | 80.8 |
| | Faizabad | 17.5 | 20.3 | 18.3 | 79.0 | 74.5 | 78.9 |
| | Mean | 48.0 | 40.2 | 47.4 | 79.0 | 74.5 | 78.9 |
| C.D. | | Var: 1.2, Var × Location: 2.6 | | | Var 1.67, Var × Location: 3.3 | | |

**Table. 8 Trials of HT/07-1329 at YSR Horticultural University, Andhra Pradesh**

| Genotypes | Total tuber yield (t/ha) | | | | Mean | % Advantage |
|---|---|---|---|---|---|---|
| | 2016-17 | 2017-18 | 2018-19 | 2019-20 | | |
| HT/07-1329 | 15.3 | 26.4 | 27.3 | 25.03 | 23.5 | |
| Kufri Surya | 6.4 | 18.1 | 23.12 | 20.36 | 17.0 | 38 |
| Kufri Jyoti/ Kufri Lima | 8.6 | 25.2 | 23.52 | 19.11 | 19.1 | 23 |

**Table 9. Performance in AICRP trials at 75 days (pooled over location)**

| Regions | HT/07-1329 | | | Kufri Lima | | | Kufri Surya | | |
|---|---|---|---|---|---|---|---|---|---|
| | TTY* | MTY** | DM%** | TTY* | MTY** | DM%** | TTY* | MTY** | DM%** |
| Northern plains | 30.5 | 29.1 | 16.8 | 27.3 | 26.4 | 16.9 | 28 | 26.1 | 16.6 |
| | Yield advantage (%) | | | 11.5 | 10.4 | | 8.8 | 11.5 | |
| Central plains | 33.1 | 28.5 | 18.1 | 31.1 | 26.5 | 17.6 | 29.4 | 24.3 | 18.1 |
| | Yield advantage (%) | | | 7 | 7.5 | | 12.6 | 17.4 | |
| Eastern plains | 21.8 | 19.8 | 17.5 | 18.4 | 16.8 | 17.5 | 19.5 | 17.9 | 17.7 |
| | Yield advantage (%) | | | 18.2 | 17.7 | | 11.3 | 10.3 | |
| G Mean | 28.5 | 25.8 | 17.5 | 25.6 | 23.2 | 17.3 | 25.6 | 22.8 | 17.5 |
| | Yield advantage (%) | | | 11.2 | 11.0 | | 11.1 | 13.3 | |

*TTY-Total tuber yield (t/ha); **MTY-Marketable tuber yield (t/ha); ***DM-Dry matter

marketable tuber yield than Kufri Lima (26 t/ha and 23 t/ha) and 11% and 13% higher total and marketable tuber yield than Kufri Surya respectively at 75 days crop duration **(Table 9).** HT/07-1329 has tuber dry matter content (18%)**.**

**Performance HT/07-1329 in AICRP at 90 days (pooled over locations):** In Northern plains, HT/07-1329 (33 t/ha and 32 t/ha) yielded 10 and 8% higher total and marketable tuber yield than the best control Kufri Lima (30 t/ ha and 29 t/ha), respectively at 90 days crop duration **(Table 12).** HT/07-1329 has tuber dry matter content (18%). In central plains, HT/07-1329 (40 t/ha and 35 t/ha) yielded 5 and 6% higher total and marketable tuber yields than the best control Kufri Lima (38 t/ ha and 33 t/ha), respectively at 90 days crop duration**.** HT/07-1329 has acceptable tuber dry matter content (20%)**.** In eastern plains, HT/07-1329 (36 t/ha and 34 t/ha) yielded 11 % higher total and marketable tuber yields than the best control Kufri Lima (32 t/ha and 30 t/ha), respectively at 90 days crop duration**.** HT/07-1329 has acceptable tuber dry matter content (18.4%)**.** The performance of over regions reflected that HT/07-1329 (36 t/ha and 34 t/ha) yielded 9% higher total and marketable tuber yield than control Kufri Lima (33 t/ha and 31 t/ha) and 15% and 16% higher total and marketable tuber yield than Kufri Surya (32 t/ha and 29 t/ ha) respectively at 90 days crop duration **(Table 10).** HT/07-1329 has tuber dry matter content (19%)**.**

***Keeping quality:*** The advanced clone HT/07-1329 possesses a long tuber dormancy period (10 weeks), comparatively less weight loss, rottage, and weight loss due to sprouts after 75 days of on-farm storage **(Table 11)**, therefore adjudged to be an excellent keeper. HT/07-1329 clearly showed excellent keeping quality it has lesser physiological and total weight loss (9%) as compared to heat tolerant variety Kufri Surya (11%) and local check Kufri Bahar (16%) at Modipuram.

**Tolerance to temperature stress and disease resistance:** The new variety Kufri Kiran (HT/07-1329) possess tolerance to high temperature stress, therefore is able to tuberize and produce a sustainable yield in a crop planted 15-20 days early than normal season, thereby fetching the remunerative price due to preference of consumers for fresh potatoes during the early season (**Table 12, 13**). HT/07-1329 is tolerant to hopper and mite burn (**Table 14**), which causes serious yield losses under heat stress conditions.

**Table 10. Performance in AICRP trials at 90 days (pooled over location)**

| Regions | HT/07-1329 | | | Kufri Lima | | | Kufri Surya | | |
|---|---|---|---|---|---|---|---|---|---|
| | TTY* | MTY** | DM%** | TTY* | MTY** | DM%** | TTY* | MTY** | DM%** |
| Northern plains | 33.3 | 31.7 | 17.6 | 30.3 | 29.2 | 17.9 | 28.8 | 27.3 | 17.8 |
| | Yield advantage (%) | | | 9.9 | 8.3 | | 15.8 | 15.9 | |
| Central plains | 39.5 | 35.1 | 20.2 | 37.7 | 33.0 | 21 | 34.8 | 30.3 | 19.9 |
| | Yield advantage (%) | | | 5 | 6.3 | | 13.4 | 15.7 | |
| Eastern plains | 35.9 | 33.7 | 18.4 | 32.2 | 30.3 | 18.3 | 31.3 | 29.4 | 18.6 |
| | Yield advantage (%) | | | 11.4 | 11.3 | | 14.7 | 14.6 | |
| G Mean | 36.2 | 33.5 | 18.7 | 33.4 | 30.8 | 19.1 | 31.6 | 29.0 | 18.8 |
| | Yield advantage (%) | | | 8.5 | 8.6 | | 14.5 | 15.5 | |

*TTY-Total tuber yield (t/ha); **MTY-Marketable tuber yield (t/ha); ***DM-Dry matter

**Table. 11 Storage behaviour of HT/07-1329 at ambient temperature (2013-14 to 2014-15)**

| Genotypes | Year | Dormancy | % spr outing at 45 days | % spr outing at 75 days | % loss due to sprouting | % Rottage | Physiological wt loss | Total wt loss % |
|---|---|---|---|---|---|---|---|---|
| HT/07-1329 | 2014-15 | >10 weeks | 6.2 | 11.2 | 0.0 | 0.0 | 9.8 | 9.8 |
| | 2013-14 | <10 weeks | 0.0 | 100.0 | 0.1 | 1.1 | 6.1 | 7.4 |
| | Mean | > 10 weeks | 3.1 | 55.6 | 0.05 | 0.6 | 8.0 | 8.6 |
| Kufri Surya | 2014-15 | >10 weeks | 25 | 55.9 | 0.04 | 0.0 | 11.2 | 11.3 |
| | 2013-14 | <10 weeks | 21.4 | 100.0 | 0.1 | 0.0 | 10 | 10.1 |
| | Mean | 10 weeks | 23.2 | 78.0 | 0.07 | 0.0 | 10.6 | 10.7 |
| Kufri Bahar | 2014-15 | <6 weeks | 100.0 | 100.0 | 0.5 | 7.4 | 11.8 | 19.2 |
| | 2013-14 | <6 weeks | 89.5 | 100.0 | 0.7 | 1.6 | 9.2 | 12.1 |
| | Mean | <6 weeks | 94.8 | 100.0 | 0.6 | 4.5 | 10.5 | 15.6 |

**Table 12. The temperature profile of AICRP locations during crop growth (2019-20)**

| Location | Date of planting | Temperature $^0$C | | Mean Temperature $^0$C | Growing degree days |
|---|---|---|---|---|---|
| | | Max | Min | | |
| | | Northern plains | | | |
| Hisar | 18-Oct | 22.8 (33.0)* | 9.7 (16.0) | 16.2 | 1056 |
| Jalandhar | 12-Oct | 20.3 (30.0) | 10.9 (20.0) | 15.6 | 1000 |
| Modipuram | 25-Sep | 27.0 (31.0) | 14.2 (23.0) | 20.6 | 1448 |
| | | Central plains | | | |
| Chindwara | 16-Nov | 24.3 (27.0) | 11.7 (14.0) | 18 | 1216 |
| Deesa | 25-Oct | 28.5 (34.0 ) | 14.7 (23.0 ) | 21.6 | 1539 |
| Raipur | 13-Nov | 27.1 (30.0) | 13.9 (15.0) | 20.5 | 1440 |
| | | Eastern plains | | | |
| Bhubaneshwar | 05-Dec | 28.3 (29.0) | 16.2 (17.0) | 22.2 | 1597 |
| Faizabad | 07-Nov | 20.6 (28.0) | 9.6 (13.0) | 15.1 | 957 |

*Figures in parenthesis are weekly mean temperatures during planting

**Table.13: Tuberization at elevated temperatures under controlled conditions**

| Genotypes | 24$^0$C/22$^0$C (Day and Night Temp) | | | 24$^0$C/24$^0$C (Day and Night Temp) | | |
|---|---|---|---|---|---|---|
| | No. of sessile Tubers | No. of stolons | Diameter of tubers (mm) | No. of sessile Tubers | No. of stolons | Diameter of tubers (mm) |
| HT/07-1329 | 4 | 5 | 5.7 | 3 | 1 | 3.9 |
| Kufri Surya | 6 | Nil | 5.4 | 3 | Nil | 4.4 |

**Table.14: Mite and hopper tolerance in HT/07-1329 during 2014 and 2015 at Modipuram**

| Insects | Damage % | | | |
|---|---|---|---|---|
| | HT/07-1329 | Kufri Surya | Kufri Bahar | Kufri Lauvkar |
| Miteburn | 10.4 | 15.6 | 18.2 | 51.8 |
| Hopperburn | 0.0 | 0.85 | 5.0 | 10.0 |

***Usage:*** Kufri Kiran is a table potato variety suitable for planting 15-20 days early than normal planting in sub-tropical North Indian plains. It produces white-cream, ovoid tubers with shallow eyes and cream flesh which leads to less peeling losses. The tubers of Kufri Kiran seldom exhibit external/internal defects and

are not susceptible to skin damage at harvest. It is easy to cook (15-20 minutes) and cooked/ boiled potatoes are free from discolouration. It possesses a pleasant flavour, mealy texture and very good organoleptic taste. The desirable tuber characteristics, excellent keeping and culinary quality of Kufri Kiran will favour its acceptance.

## AGRONOMIC MANAGEMENT

***Planting time:*** 15-20 days early than the main season planting of the region. For seed potatoes, plant the crop in the main season.

***Planting:*** *Seed rate:* 35-40 q/ha. *Seed size*: 40-60 g. *Spacing:* Plant spaced at 20 cm in 60 cm (planting depth: 10-12 cm) rows provides optimum tuber size distribution for the production of desirable tuber size for seed or table potatoes.

***Manure and fertilizer:*** Apply 10-15 t/ha FYM at the time of planting. For seed crop, the dose of 180, 80, and 100 kg/ha of nitrogen, phosphorous and potassium, respectively is recommended, where half of N and full $P_2O_5$ and $K_2O$ is applied at planting and the remaining half N is given at earthing-up. Apply 180 kg N, 40 kg $P_2O_5$ and 100 kg $K_2O$/ ha respectively for 75 days ware crop under moderate fertility level at Modipuram. Nitrogen is best applied in split doses, 90 kg at the time of planting and 90 kg at the time of earthing up. Nutrient management should be done as per soil test data and regional recommendations for optimum productivity of this variety.

***Irrigations:*** Pre-sowing irrigation is recommended for uniform emergence otherwise first irrigation should be given 4-6 days after planting. Post planting irrigations is recommended at 7-10 days interval in sandy loam soil and 10-12 days in heavy soil. Germination, stolon formation and tuber bulking are critical stages for moisture. Local recommended irrigation schedules may be followed.

***Plant Protection Measures:*** For management of cutworms, white grubs, beetles and leaf eating caterpillars, apply cartap hydrochloride 4G @20 kg/ha during earthing-up. It will also take care of sucking pests like leaf hopper and aphids. For seed crops to manage white flies and aphid vectors, place yellow sticky traps (15x30 $cm^2$ size) just above the canopy height @ 60 traps/ha at equidistance from each other for mass trapping of white flies/aphids. Seed treatment with imidacloprid (200SL) @ 0.04% (4 ml/10 lit) for 10 minutes before planting. First spray with imidacloprid (200SL) @ 0.03% (3 ml/10 lit of water) at 85% crop emergence. Second spray with thiamethoxam (25 WG) @ 0.05% (5 gm/10 lit of water) after 10-15 days of the first spray. For control of late blight, prophylactic spray with mancozeb or propineb or chlorothalonil @ 0.2% (20 gm/10 l of water) followed by need based application of cymoxanil + mancozeb or dimethomorph + mancozeb or fenamidone + mancozeb @ 0.3% (30 gm/10 l of water is required.

## ADAPTABILITY

Kufri Kiran (HT/07-1329) has performed well in primary evaluation trials at Modipuram (UP), Ladol (Gujarat), Pune (Maharashtra) and multi-location trials conducted under AICRP in all major regions and has been recommended for cultivation in Indian plains (north, central, eastern), plateau region including West Godavari District of Andhra Pradesh (Rao *et al,* 2018 and Rao *et al*, 2018a). Kufri Kiran produced up to 9% higher tuber yield as compared to Kufri Lima and 16% higher as compared to heat tolerant variety Kufri Surya. It produces attractive white-cream ovoid tubers with shallow eyes and possesses excellent keeping quality. The cultivation of Kufri Kiran in early season planting, warmer and non-traditional areas

would help in expanding potato areas and meeting the consumer demand for fresh potatoes. It would also help farmers to get remunerative prices for the produce, thereby improving the farmer's economic conditions.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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# CHARACTERIZATION OF ANDIGENA ACCESSIONS FOR BIOTIC STRESS RESISTANCE USING LINKED MOLECULAR MARKERS

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**ABSTRACT: In the current study, 72 andigena accessions were screened for resistance to late blight, viruses (PVY and PVX), and potato cyst nematodes (PCNs) using gene-based linked markers. R1 gene was only present in one accession, JEX-A/668. Whereas two accessions, JEX-A/459 and JEX-A/616, showed the presence of the R2 gene. The R3a gene was not present in any of the accessions. The R3b gene was also amplified in the JEX-A/42, JEX-A/107, and JEX-A/459 accessions. In PVY resistance screening, the YES3-3A marker was found in 50 accessions. In comparison, 40 accessions tested positive for the STM0003 marker, which indicates the presence of the *Rysto* gene, whereas 14 accessions tested positive for the RYSC3 marker. In 9 and 20 accessions, respectively, the markers 1Rx1 and 106Rx2, which were connected to the extreme resistance genes Rx1 and Rx2 for PVX resistance, were discovered. Both 1Rx1 and 106Rx2 markers were discovered in six accessions (JEX-A/232, JEX-A/267, JEX-A/638, JEX-A/683, JEX-A/1061, and JEX-A/1092). *Globodera* spp. resistance screening revealed that 17 out of 72 accessions tested positive for the marker TG689. None of the accessions was positive for the SPUD1636 marker. Furthermore, the expected-size bands for the GPA2-1 and GPA2-2 markers, 1120 and 452 bp, respectively, were found in 15 separate accessions. Both markers show the presence of the Gpa2 locus, which almost completely confers resistance to one or more pathotypes of *G. pallida*.**

**KEYWORDS:** Disease Resistance, *Globodera pallida, Phytophthora infestans, Potato,* Marker-Assisted Selection (MAS)

## INTRODUCTION

The potato is one of the most important non-cereal food crops in the world. In terms of human consumption, it is the third most important crop after wheat and rice. Since potatoes are propagated asexually in the form of tubers, they are prone to a variety of biotic stresses, such as late blight, PCN, and many viruses (Bhardwaj *et al*., 2019). Every year billion-dollar losses in potatoes are caused by the most destructive disease late blight, which is responsible for the complete destruction of the potato crop in severe cases. Wild potato species have been found to have quantitative or field resistance to late blight. In the past decade, more than 60 late blight-resistant genes were mapped on different potato species (Mangal *et al*., 2022). Resistance genes to late blight were mapped on wild species *S. demissum* (*R1-R11, Rpi-dmsf1*), *S. pinnatisectum* (*Rpi1, Rpi2, Pi-Blatt*), *S. bulbocastanum* (*Rpi-blb1-Rpi-blb3, Rpi-bt1, Rpi-apbt*), *S. hjertingii* (*Rpi-hjt1.1, Rpi-hjt1.2, Rpi-hjt1.3*), *S. chacoense* (*Rpi-chc1, Rpi-chc2*) etc (Paluchowska *et al*., 2022; Tiwari *et al*., 2013; Yang *et al*., 2017). To date, many markers linked to LB resistance genes have been discovered like R1AS linked to R1 gene (Ballvora *et al*., 2002), Q133 (SCAR) for *Rpi-ber1* gene (Tan *et al*., 2010), R2AS for *Rpi-abpt* gene (Kim *et al*., 2012), and SpTG572 (SCAR) for *Rpi2* gene (Yang *et al*., 2017) etc.

Like late blight, viruses too pose a serious problem in potatoes as compared to other diseases because of their vegetative propagation and transmission of viruses from

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tuber to tuber in subsequent generations. PVY resistance genes $Ry_{adg}$ (*S. tuberosum* sp. *andigenum*), $Ry_{sto}$ and $Ry_{fsto}$ (*S. stoloniferum*) and $Ry_{hcu}$ (*S. hougasii*) have been reported to impart extreme resistance to this virus (Cockerham, 1970; Flis *et al*., 2005; Kasai *et al*., 2000; Song *et al*., 2005). Likewise, other genes i.e., $Ny_{tbr}$, *Ny-1*, $Nc_{spl}$, $Nc_{tbr}$ and $Ny_{dms}$ were also mapped which provide hypersensitive reaction to PVY (Celebi-Toprak *et al*., 2002; Szajko *et al*., 2008). For PVX extreme (*Rx1, Rx2,* $Rx_{adg}$, $Rx_{acl}$) and hypersensitive resistance genes ($Nx_{phu}$, $Nx_{tbr}$, $Nx_{chc}$, *Nb*) were mapped on different wild and cultivated species (Ahmadvand *et al*., 2013; Marano *et al*., 2002; Ritter *et al*., 1991; Tommiska *et al*., 1998). Markers linked to PVX resistance genes are as follows: 1Rx1 for *Rx1* gene, 106Rx2 marker for *Rx2* gene (Ahmadvand *et al*., 2013).

The third major problem in potatoes worldwide is Potato Cyst Nematodes (*Globodera pallida* and *G. rostochiensis*), which cause great losses to agriculture worldwide (Sood *et al*., 2022). Resistance genes to different pathotype of *G. pallida* have been reported in different species like *S. multidissectum* (*H2*), *S. tuberosum* ssp. *andigena* (*H3, Gpa2,* $GpaIV^{s}_{adg}$), *S. vernei* (*Gpa5, Gpa6*), *S. tarijense* ($GpaXI^{1}_{tar}$) (Moloney *et al*., 2010; Van Der Voort *et al*., 1997; Strachan *et al*., 2019; Van Der Voort *et al*., 2000). Likewise, resistance genes to different pathotypes of *G. pallida* were mapped in different species like *S. tuberosum* ssp. *andigena* (*H1*), *S. spegazzinii* (*Gro1-4, Gro1.2, Gro1.3, Gro1.4*), *S. vernei* (*Gro 6*) etc (Bakker *et al*., 2004; Jacobs *et al*., 1996; Kreike *et al*., 1993, 1996; Paal *et al*., 2004). Several molecular markers linked to PCN resistance genes have been found, which can be used for marker assisted selection (MAS). Markers linked to known PCN resistance genes are TG689 (SCAR) for *H1* gene, SNP based HC marker for *Gpa5_vrn_QTL*, SPUD1636 for *Gpa5_QTL* and XO2 for *GroVI* gene (Asano *et al*., 2012; Bryan *et al*., 2002; Jacobs *et al*., 1996). It has been demonstrated in several studies that markers tightly linked to the aforementioned resistance genes can improve the efficiency of potato breeding for resistance to biotic stresses (Sharma *et al*., 2014; Sudha *et al*., 2016). Accordingly, the present study was designed to identify potato accessions that possess multiple disease resistance genes that can be exploited in biotic stress resistance potato breeding program.

## MATERIALS AND METHODS

The plant material comprising 72 andigena accessions maintained at the ICAR-Central Potato Research Station, Jalandhar, Punjab were used for molecular characterization using late blight, viruses (PVY and PVX) and PCN resistance markers. The collection included exotic potato andigena accessions imported from various countries and used as parental lines for varietal development in India (Table 1).

### DNA extraction and PCR assay

Total genomic DNA isolation from young leaves was carried out using a Qiagen Kit. DNA concentration was determined using agarose gel electrophoresis on 0.8% agarose gel and a nanodrop spectrophotometer (Thermo Scientific, US). Molecular characterization of late blight resistance was performed using the CosA, R2, R3 1380, and cLET5E4 markers. Likewise, genetic analysis of viruses (PVY and PVX) resistance was done through RYSC3, STM0003, YES3-3A, 1Rx1, and 106Rx2 markers. The molecular validation for *G. rostochiensis* resistance was carried out using TG689 and Gro-VI-XO2 markers, whereas *G. pallida* resistance was evaluated using HC, SPUD1636, GPA2-1, and GPA2-2 markers. Other details of the markers, marker type, and product size used for screening are presented in Table 2.

A Thermal Cycler Applied Biosystems was used to run PCR performed in 20 µl reaction volume, where 2 µl template DNA, 1 µl each of forward and reverse primers, 10 µl of 2x PCR master mix and rest 6 µl of distilled water. The amplified fragments were resolved

**Table 1: List of andigena accessions used for the study**

| S. No. | Accession Name | Donor No | Source | S.No. | Accession Name | Donor No | Source |
|---|---|---|---|---|---|---|---|
| 1 | JEX-A/10 | NA | UK | 37 | JEX-A/379 | PI243405 | USA |
| 2 | JEX-A/14 | PI186180 | USA | 38 | JEX-A/380 | PI243405 | USA |
| 3 | JEX-A/15 | PI186180 | USA | 39 | JEX-A/390 | PI243406 | USA |
| 4 | JEX-A/19 | PI186178 | USA | 40 | JEX-A/457 | PI243418 | USA |
| 5 | JEX-A/21 | PI186179 | USA | 41 | JEX-A/459 | PI243418 | USA |
| 6 | JEX-A/26 | PI186179 | USA | 42 | JEX-A/468 | PI243420 | USA |
| 7 | JEX-A/30 | PI197933 | USA | 43 | JEX-A/498 | PI243424 | USA |
| 8 | JEX-A/42 | PI225628 | USA | 44 | JEX-A/506 | PI243424 | USA |
| 9 | JEX-A/45 | PI225628 | USA | 45 | JEX-A/513 | PI243429 | USA |
| 10 | JEX-A/58 | PI225632 | USA | 46 | JEX-A/539 | PI243430 | USA |
| 11 | JEX-A/76 | PI230473 | USA | 47 | JEX-A/595 | PI243439 | USA |
| 12 | JEX-A/79 | PI230473 | USA | 48 | JEX-A/612 | PI243440 | USA |
| 13 | JEX-A/93 | PI232839 | USA | 49 | JEX-A/616 | PI243444 | USA |
| 14 | JEX-A/107 | PI233981 | USA | 50 | JEX-A/617 | PI243446 | USA |
| 15 | JEX-A/122 | PI233988 | USA | 51 | JEX-A/638 | PI243447 | USA |
| 16 | JEX-A/132 | PI234002 | USA | 52 | JEX-A/668 | PI243470 | USA |
| 17 | JEX-A/164 | PI243394 | USA | 53 | JEX-A/683 | PI243471 | USA |
| 18 | JEX-A/189 | PI243411 | USA | 54 | JEX-A/705 | PI245320 | USA |
| 19 | JEX-A/197 | PI243418 | USA | 55 | JEX-A/707 | PI245783 | USA |
| 20 | JEX-A/198 | PI243418 | USA | 56 | JEX-A/708 | PI245186 | USA |
| 21 | JEX-A/199 | PI243418 | USA | 57 | JEX-A/763 | PI255496 | USA |
| 22 | JEX-A/202 | PI243420 | USA | 58 | JEX-A/801 | PI280883 | USA |
| 23 | JEX-A/215 | PI242429 | USA | 59 | JEX-A/804 | PI280883 | USA |
| 24 | JEX-A/216 | PI243431 | USA | 60 | JEX-A/827 | PI280912 | USA |
| 25 | JEX-A/232 | PI243374 | USA | 61 | JEX-A/865 | NA | N/A |
| 26 | JEX-A/267 | PI243380 | USA | 62 | JEX-A/907 | CPC1673 | UK |
| 27 | JEX-A/274 | PI243381 | USA | 63 | JEX-A/912 | CIPC700939 | PER |
| 28 | JEX-A/275 | PI243381 | USA | 64 | JEX-A/917 | CIPC700939 | PER |
| 29 | JEX-A/288 | PI243385 | USA | 65 | JEX-A/920 | CIPC700939 | PER |
| 30 | JEX-A/296 | PI243389 | USA | 66 | JEX-A/947 | CIPC701947 | PER |
| 31 | JEX-A/298 | PI243389 | USA | 67 | JEX-A/1038 | CIPC702151 | PER |
| 32 | JEX-A/299 | PI243389 | USA | 68 | JEX-A/1046 | CIPC702151 | PER |
| 33 | JEX-A/316 | PI243394 | USA | 69 | JEX-A/1061 | CIPC701985 | PER |
| 34 | JEX-A/317 | PI243394 | USA | 70 | JEX-A/1081 | CIPC702028 | PER |
| 35 | JEX-A/329 | PI243296 | USA | 71 | JEX-A/1092 | CIP700116 | PER |
| 36 | JEX-A/361 | PI243403 | USA | 72 | JEX-A/1152 | CIP700178 | PER |

**Table 2: Details of the markers used for screening**

| Biotic stress | Genes | Marker | Marker type | Fragment size (bp) | Primer sequence (5′ to 3′) | Reference |
|---|---|---|---|---|---|---|
| Late blight | *R1* | Cos A | SCAR | 250 | F-CTCATTCAAAATCAGTTTTGATC<br>R-GAATGTTGAATCTTTTTGTGAAGG | Gebhardt *et al.* (2004) |
| | *Rpi-abpt* | R2 | SCAR | 686 | F- ACGGCTTCTTGAATGAA<br>R- GCTCCTGATACGATCCATG | Kim *et al.* (2012) |
| | *R3a* | R31380 | SCAR | 1380 | F-GCTTCCGACATGTATTGATCTCCC<br>R-GGCAGCCACTTCAGCTTCTTACAG | Sokolova *et al.* (2010) |
| | *R3b* | cLET5E4 | CAPS | 310 | F-CCAGGCATGCTCAATTTGGAGT<br>R-TTCCCTGTTTGGACTACTTGTGGA | Huang *et al.* (2005) |
| | $Ry_{adg}$ | RYSC3 | SCAR | 320 | F-ATACACTCATCTAAATTTGATGG<br>R-AGGATATACGGCATCATTTTTCCGA | Kasai *et al.* (2000) |
| | $Ry_{sto}$ | STM0003 | SSR | 111 | F-GGAGAATCATAACAACCAG<br>R-AATTGTAACTCTGTGTGTGTG | Valkonen *et al.* (2008) |
| PVY | $Ry_{sto}$ | YES3-3A | STS | 341 | F-TAACTCAAGCGGAATAACCC<br>R-AAATTCACCTGTTTACATGCTTCTTGTG | Song and Schwarzfischer (2008) |
| | *Rx1* | 1Rx1 | SCAR | 974 | F- GGAGAAATCCTGCAATATAAT<br>R- CGACCGAACTTACATTTTCCC | Ahmadvand *et al.* (2013) |
| PVX | *Rx2* | 106Rx2 | SCAR | 543 | F- GGAGAAATCCTGCAATGTAAC<br>R- CTTGTCAAAGAAAGAAGGCCT | |
| | *Gpa5 QTL* | SPUD 1636 | | 226 | F-GTGCGCACAGGGTAAAACC<br>R-ACCTTAGCGGATGAAAGCC | Bryan *et al.* (2002) |
| | *Gpa2* | GPA2-1 | STS | 1120 | F- TTTAGCACGGAATGTGGGGA<br>R- GTTTCCCCATCAAAACTCAC | Asano *et al.* (2012) |
| *G. pallida* | *Gpa2* | GPA2-2 | STS | 452 | F- GCACTTAGAGACTCATTCCA<br>R- ACAGATTGTTGGCAGCGAAA | Asano *et al.* (2012) |
| | *RGp5-vrnHC* | HC | SNP | 276 | F-ACACCACCTGTTTGATAAAAAACT<br>R-GCCTTACTTCCCTGCTGAAG | Sattarzadeh *et al.* (2006) |
| *G. rostochiensis* | *H1* | TG 689 | SCAR | 141 | F-TAAAACTCTTGGTTATAGCCTAT<br>R-CAATAGAATGTGTTGTTTCACCAA | Milczarek *et al.* (2011) |
| | *GroVI* | Gro-VI-XO2 | SCAR | 854 | F-CCACCAAACCCATAAAGCTGC<br>R-TGTGAATTGGTATGAATCTGCAACC | Jacobs *et al.* (1996) |

on 1.2% agarose gel depending on the size of the specific fragment, using a horizontal gel electrophoresis system. The screening was done based on the presence or absence of the desired bands. The presence of the band was scored as + (plus) and absence was scored as – (minus).

## RESULTS AND DISCUSSION

Marker assisted selection (MAS) has numerous advantages including selection in early generations, reduced load of handling large progenies in advanced generations, speed, efficiency, cost reduction and resources optimization over phenotypic screening in the breeding program (Bhardwaj *et al.*, 2019; Slater *et al.*, 2013). Validated robust markers, previously identified were deployed for late blight, PVY, PVX, and PCN resistance screening of seventy-two andigena accessions. Four late blight, R genes were deployed and it was found that the *R1* gene was found in only one accession JEX-A/668. Two accessions JEX-A/459 and JEX-A/616 showed the presence of the *R2* gene. None of the accessions showed the presence of the $R_3a$

gene. Likewise, the $R_3b$ gene was amplified in three accessions namely, JEX-A/42, JEX-A/107 and JEX-A/459. Genotyping of 72 accessions using LB resistance gene-linked markers revealed 5 accessions with atleast one or the other resistance gene present in them (Table 3; Fig. 1). Accessions JEX-A/459 exhibited the presence of two genes i.e., *R2* and $R_3b$ simultaneously. All these late blight resistance genes have been introgressed from wild species *Solanum demissum*. A single R gene may not provide complete or extreme resistance to the disease, and thus, it may be necessary to have more than one R gene or a combination of resistant genes to provide total or extreme resistance. As a result, those accessions that show the presence of multiple genes for late blight can be used in the potato breeding program. Since, andigena group is adapted to short-day conditions; late blight disease tends to occur during the later stages of the crop. This may be one of the reasons why very few resistance genes have been developed in these accessions for this disease. In our study, only five accessions out of 72 showed the presence of R genes.

The PVY resistance screening carried out using $Ry_{adg}$ and $Ry_{sto}$ genes linked markers, RYSC3, YES3-3A and STM0003 revealed that the YES3-3A marker was present in 50 accessions (Table 3; Fig. 2). RYSC3 marker was found in 14 accessions while forty accessions were found positive for STM0003 marker indicating the presence of the $Ry_{sto}$ gene in them (Table 3). Genotyping of 72 accessions using PVY resistance gene-linked markers revealed 51 accessions with atleast one or the other marker present in them. Similarly, 29 accessions were found to contain at least two resistant genes, and 12 accessions contained at least three resistant genes for PVY and PVX. $Ry_{adg}$ and $Ry_{sto}$ genes were mapped on *S. tuberosum* sp. *andigenum* and *S. stoloniferum* species respectively which impart extreme resistance to PVY (Cernák *et al*., 2008; Dalla Rizza *et al*., 2006; Kasai *et al*., 2000; Song and Schwarzfischer, 2008). As the andigena accessions have co-evolved in virus-infected hot spots, they are likely to possess virus resistance genes. As a result, more resistance genes for viruses were expected in the collection. These linked markers are very useful for MAS and the introgression of $Ry_{adg}$ and $Ry_{sto}$ genes into potato breeding lines. Valkonen *et al*. (2008) used $Ry_{sto}$ genes in the independent breeding populations with the same PCR-based markers and found that markers specifically detected independent European potato cultivars that express extreme resistance to PVY derived from *S. stoloniferum*. PVY resistance clones can be rapidly selected during early generations of breeding programs using

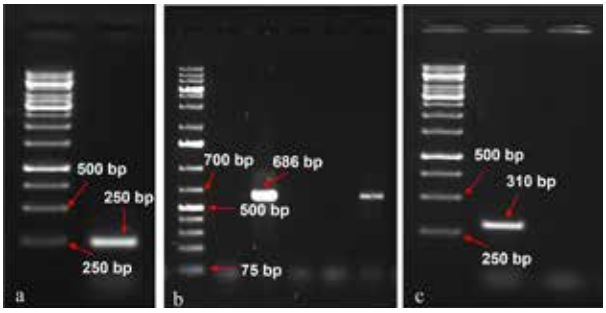



*Fig. 1: Agarose gel electrophoresis showing the PCR products of different late blight resistant genes/markers a) CosA marker- 250bp, 1kb marker b) R2 marker – 686bp, 1kb plus marker c) cLET5E4 marker-310bp, 1kb marker*

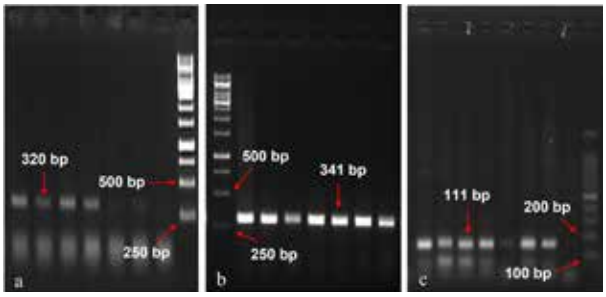



*Fig. 2: PCR products of different PVY resistant genes/markers tested on 1.2% agarose gel a) RYSC3 marker - 320bp, 1kb marker b) YES3-3A marker- 341bp, 1kb marker c) STM0003 marker- 111bp, 100bp marker*

**Table 3: Genotypic data of all andigena accessions used for the study**

| Accessions | Late blight | | | | Viruses | | | | | | PCN | | | | Total number of resistance genes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | PVY | | | PVX | | | | | | | |
| | R1 | R2 | R3a | R3b | YES3-3A | RYSC3 | STM0003 | RX1 | RX106 | TG 689 | HC | Gro-VI-XO2 | GPA2-1 | GPA2-2 | |
| JEX-A/10 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/14 | - | - | - | - | - | - | - | - | - | + | - | - | - | - | 1 |
| JEX-A/15 | - | - | - | - | - | - | - | - | - | + | - | - | - | - | 1 |
| JEX-A/19 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/21 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/26 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/30 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/42 | - | - | - | + | + | - | + | - | + | + | - | - | - | - | 5 |
| JEX-A/45 | - | - | - | - | + | - | + | - | - | - | - | + | - | - | 3 |
| JEX-A/58 | - | - | - | - | - | - | - | - | - | - | - | - | + | + | 2 |
| JEX-A/76 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/79 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/93 | - | - | - | - | - | - | + | - | - | - | - | - | - | - | 1 |
| JEX-A/107 | - | - | - | + | - | - | - | - | - | - | - | - | - | - | 1 |
| JEX-A/122 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/132 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/164 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/189 | - | - | - | - | + | - | + | - | - | + | + | - | - | - | 4 |
| JEX-A/197 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/198 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/199 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/202 | - | - | - | - | + | + | + | - | + | + | + | - | + | + | 8 |
| JEX-A/215 | - | - | - | - | - | - | - | + | - | + | + | - | - | - | 3 |
| JEX-A/216 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/232 | - | - | - | - | - | - | - | + | + | - | - | - | + | + | 4 |
| JEX-A/267 | - | - | - | - | + | - | + | + | + | - | + | - | + | + | 7 |
| JEX-A/274 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/275 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/288 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/296 | - | - | - | - | + | - | - | - | + | + | - | - | + | + | 5 |
| JEX-A/298 | - | - | - | - | + | - | - | - | + | + | + | - | + | + | 6 |
| JEX-A/299 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/316 | - | - | - | - | + | - | + | - | - | - | - | + | - | - | 3 |
| JEX-A/317 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/329 | - | - | - | - | + | - | - | - | + | - | - | - | - | + | 3 |
| JEX-A/361 | - | - | - | - | + | - | - | - | + | + | - | - | + | + | 5 |
| JEX-A/379 | - | - | - | - | - | - | - | - | - | + | - | - | - | - | 1 |

| Accessions | Late blight | | | | Viruses | | | | | PCN | | | | | Total number of resistance genes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | PVY | | | PVX | | | | | | | |
| | R1 | R2 | R3a | R3b | YES3-3A | RYSC3 | STM0003 | RX1 | RX106 | TG 689 | HC | Gro-VI-XO2 | GPA2-1 | GPA2-2 | |
| JEX-A/380 | - | - | - | - | + | - | + | - | - | - | + | - | - | - | 3 |
| JEX-A/390 | - | - | - | - | + | + | + | - | - | - | - | + | - | - | 4 |
| JEX-A/457 | - | - | - | - | + | - | + | - | + | + | + | - | + | + | 7 |
| JEX-A/459 | - | + | - | + | + | + | + | + | - | - | - | - | - | - | 6 |
| JEX-A/468 | - | - | - | - | + | + | - | - | + | - | + | - | - | - | 4 |
| JEX-A/498 | - | - | - | - | + | - | - | - | - | + | + | - | - | - | 3 |
| JEX-A/506 | - | - | - | - | + | + | + | - | + | + | + | - | + | + | 8 |
| JEX-A/513 | - | - | - | - | + | - | - | + | - | - | - | - | - | - | 2 |
| JEX-A/539 | - | - | - | - | + | + | - | - | - | - | - | + | - | - | 3 |
| JEX-A/595 | - | - | - | - | + | - | - | - | - | - | - | + | - | - | 2 |
| JEX-A/612 | - | - | - | - | + | - | - | - | - | - | - | + | - | - | 2 |
| JEX-A/616 | - | + | - | - | + | + | + | - | + | - | - | - | - | - | 5 |
| JEX-A/617 | - | - | - | - | + | - | + | - | - | + | - | - | - | - | 3 |
| JEX-A/638 | - | - | - | - | + | - | + | + | + | + | - | + | + | + | 8 |
| JEX-A/668 | + | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 |
| JEX-A/683 | - | - | - | - | + | - | + | + | + | + | - | + | + | + | 8 |
| JEX-A/705 | - | - | - | - | + | - | + | - | + | - | - | - | - | - | 3 |
| JEX-A/707 | - | - | - | - | + | - | + | - | + | - | - | - | - | - | 3 |
| JEX-A/708 | - | - | - | - | + | - | + | - | - | - | - | + | - | - | 3 |
| JEX-A/763 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/801 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/804 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/827 | - | - | - | - | + | - | - | - | - | - | - | - | - | - | 1 |
| JEX-A/865 | - | - | - | - | - | - | - | - | + | + | - | - | + | - | 3 |
| JEX-A/907 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| JEX-A/912 | - | - | - | - | + | + | + | - | - | - | - | - | - | - | 3 |
| JEX-A/917 | - | - | - | - | - | - | - | - | - | - | - | + | - | - | 1 |
| JEX-A/920 | - | - | - | - | + | + | + | - | - | - | - | + | - | - | 4 |
| JEX-A/947 | - | - | - | - | - | - | - | - | - | - | - | + | - | - | 1 |
| JEX-A/1038 | - | - | - | - | + | - | + | - | - | - | - | - | - | - | 2 |
| JEX-A/1046 | - | - | - | - | + | + | + | - | - | - | - | - | - | - | 3 |
| JEX-A/1061 | - | - | - | - | + | + | + | + | + | - | - | - | + | + | 7 |
| JEX-A/1081 | - | - | - | - | + | + | + | - | - | - | - | - | - | - | 3 |
| JEX-A/1092 | - | - | - | - | + | + | + | + | + | - | - | - | + | + | 7 |
| JEX-A/1152 | - | - | - | - | + | + | + | - | + | - | - | - | + | + | 6 |

MAS. Marker 1Rx1 and 106Rx2 which were linked to extreme resistance genes *Rx1* and *Rx2* for PVX resistance, were found in 9 and 20 accessions, respectively. Six accessions (JEX-A/232, JEX-A/267, JEX-A/638, JEX-A/683, JEX-A/1061 and JEX-A/1092) were found to have both 1Rx1 and 106Rx2 markers (Fig. 3).

The screening for resistance to *Globodera* spp. showed that 17 out of 72 accessions were positive for marker TG689 linked with gene *H1* (Table 3). TG689 is a robust marker and has been used in many studies for the selection of the resistance to *Globodera rostochiensis* (Douches *et al.*, 2010 and Milczarek *et al.*, 2011). The marker SPUD1636 associated with the chromosomal segment containing the *S. vernei* derived QTL (*Gpa5* and *Gpa6*) was not amplified in any of the accessions analyzed in the present study. The SNP marker HC was found in 10 accessions, which is a diagnostic marker for *RGp5-vrnHC* QTL and imparts partial resistance to *Pa2/3* pathotype of *G. pallida*. Likewise, twelve accessions showed the presence of

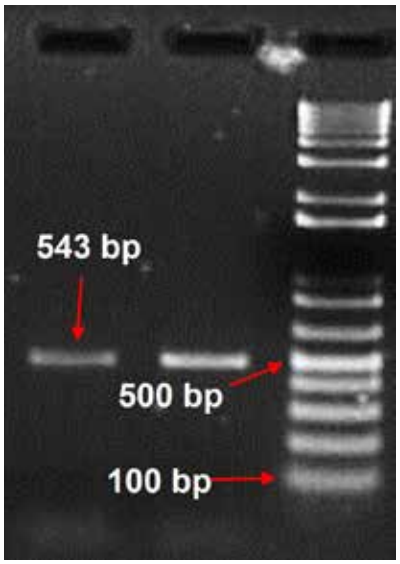



*Fig. 3: Agarose gel electrophoresis showing the PCR product of 106Rx2 marker of PVX resistant gene Rx2 (Marker – 100bp plus, desired gene product size-543bp)*

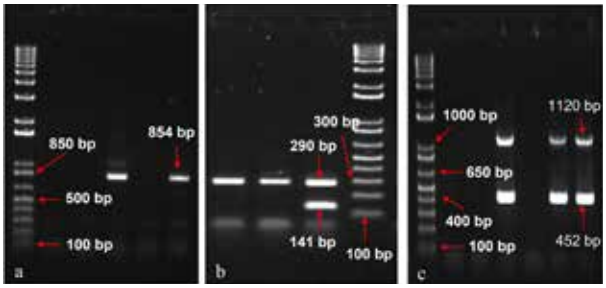



*Fig. 4: Agarose gel profile of different PCN resistant genes/ markers a) Gro-VI-XO2 marker-854bp, 1kb marker b) TG689 marker-141bp, 1kb plus marker, BCH internal control-290bp c) GPA 2-1-1120bp and GPA 2-2-452bp, 1kb plus marker*

an Gro-VI-XO2 marker which detects *Gro-VI* QTL resistance to *G. rostochiensis*. Further, GPA2-1 and GPA2-2 markers were detected in 15 different accessions with expected-size bands 1120 and 452 bp, respectively. Both markers detect a *Gpa2* locus that nearly confers absolute resistance to one or more pathotypes of *G. pallida* (Asano *et al.*, 2012). Genotyping of 72 accessions using PCN resistance gene-linked markers revealed that 36 accessions with atleast one or the other marker present in them. Similarly, 9 (JEX-A/58, JEX-A/189, JEX-A/215, JEX-A/232, JEX-A/498, JEX-A/865, JEX-A/1061, JEX-A/1092 and JEX-A/1152) accessions were found to contain two resistant genes, three (JEX-A/267, JEX-A/296 and JEX-A/361) accessions contained three resistant genes, and 6 (JEX-A/202, JEX-A/298, JEX-A/457, JEX-A/506, JEX-A/638 and JEX-A/683) accessions contained four resistant genes linked to PCN (Table 3; Fig. 4).

A maximum of eight resistance genes together were identified in four accessions (JEX-A/202, JEX-A/506, JEX-A/638 and JEX-A/683) out of all 72 accessions studied for biotic stresses. Similarly, seven resistance genes were identified in another four andigena accessions (JEX-A/267, JEX-A/457, JEX-A/1061 and JEX-A/1092). Based on molecular markers we identified 53 andigena

accessions possessing at least two genes for resistance to late blight, PVY and/or PCN. A number of studies have shown that markers tightly linked to the genes encoding the resistance to biotic stresses can improve the efficiency of potato breeding for resistance to late blight, virus, and PCN (Bhardwaj *et al*., 2019; Dalamu *et al*., 2023; Mangal *et al*., 2023; Sood *et al*., 2022; Sudha *et al*., 2016).

## CONCLUSION

Potato breeders have always strived to develop varieties that are capable of withstanding multiple biotic stresses. Unfortunately, because of the polygenic nature of resistances, tetrasomic inheritances, and inadequate screening techniques to screen large segregating progenies, selection of such 'miracle' genotypes remained mostly elusive. The molecular markers could be used for preliminary screening of large populations for biotic stresses and selection of desirable progeny genotypes without conducting extensive phenotypic testing. In the present study, JEX-A/42, JEX-A/107, JEX-A/459, JEX-A/616, JEX-A/683 were carrying resistance genes for late blight, whereas the genotypes JEX-A/202, JEX-A/506, JEX-A/638, and JEX-A/683 possessed maximum number of resistance genes for PVY, PVX and PCN. The lines identified in the current study through markers will be validated for phenotypic reaction for different biotic stress traits before their utilization in the breeding program.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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# BIODIVERSITY OF WEEDS IN POTATO (*SOLANUM TUBEROSUM*) IN PANGALENGAN AND CIKAJANG SUB-DISTRICTS OF INDONESIA

**Umiyati U*, Denny Kurniadie and Intan Ratna Dewi Anjarsari**

**ABSTRACT: Potato is one of the horticulture crops with the highest economic worth and the steadiest market interests. Weeds can affect agricultural output through competition for nutrients and water, sunlight for photosynthesis, and growing space. This study attempts to comprehend the proliferation of weeds in potato cultivation in West Java's Potato Centers of Pangalengan and Cikajang Subdistricts. The study was done between December 2020 and February 2021 using survey and vegetation analysis techniques. The vegetative analysis demonstrates that the diversity of weeds in potato cropping in the Pangalengan and Cikarang Subdistricts led to precise results. Four kinds of grassy weeds, two sedges, and eight broadleaf weeds were discovered in potato cropping throughout the Pangalengan Subdistrict. Two species of grassy weeds, two species of sedges, and eleven species of broadleaf weeds were discovered in the potato cropping across the Cikarang Subdistrict, which contained a total of fifteen species. The weeds with the greatest SDR (Summed Dominance Ratio) values in these two regions were Cyperus rotundus and Eleusine indica. The species diversity index value (H'), which fell into the medium category, and the community coefficient index value (C), which has significant degrees of difference, also revealed differences in diversity.**

**KEYWORDS:** Cikajang Sub-district, Pangalengan Sub-district, potato, vegetation analysis

## INTRODUCTION

Potatoes (*Solanum tuberosum* L.) are one of Indonesia's most important horticultural products. However, its manufacturing rate has yet to reach its optimal level. In 2015, potato production in Indonesia reached 1,219,269 tons, evenly distributed across all provinces. In 2018, according to the same data from the Indonesian Central Statistics Bureau, West Java was Indonesia's most significant producer of potatoes, with a net production of 259,228 tons. Despite this, the trend of potato output in West Java is downward. According to data from the Indonesian Central Statistics Bureau[1], in 2018, net production decreased from 261,967 tons in 2012 to 245,337 tons in 2014.

Culturing superior varieties with high productivity and disease resistance features and controlling plant pests can improve potato productivity (del Mar Martínez-Prada *et al*., 2021). The existence of other pests like weeds in agricultural land will cause competition in using factors of growth between cultivated plants and weeds (Mukhtar Iderawumi, 2018). Weeds can reduce crop yield through competition regarding needs for nutrients and water, sunray for photosynthesis, and growing space (Korav *et al*., 2018). Weeds in the cultivation area can cause a loss in quality and quantity of production.

Weeds are one of the causing problems of potato production decrease. They refer to plants inhibiting or harming cultivation that, by extension, bother or harm human interests so that humans try to control them. Types of weeds include grassy weeds, sedges, and broadleaf weeds (Meirista *et al*., 2018).

Various factors influence the types and diversity of weeds in the land, including soil

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or soil humidity and crown condition. Cultural control practices will influence the degrees of competition between weeds to cultivated plants. It is further stated that the density of weeds growing in agricultural lands varies according to the season. During the rainy season, water reserves are plenty and, in turn, increase weed population, and vice versa (Bir *et al*., 2014).

The diversity of weeds is strongly influenced by the environment in which such weeds grow. Several factors that affect weed diversity are the type and level of soil fertility, temperature, the height of the premises, mode of cultivation, seeding methods, water management, tillage, and weed control (Cahyanti & Etica, 2020; Kurniadie *et al*., 2018).

Weed diversity and distribution are strongly influenced by various factors such as climate and meteorological conditions (length of vegetative season, air temperature, rate, and rainfall distribution). In addition, cultivation techniques such as loosening the soil can affect the spread, variability, and density of weed growth in the yard (Juraimi *et al*., 2011; Romaneckas *et al*., 2021)60 and 90 DAS. The difference in the level of condition factors that support the growth and spread of weeds causes the diversity of weed vegetation in each country to be different (Rahayu *et al*., 2019)Bantul, Yogyakarta from December 2016 to May 2017. The study used a completely randomized block design with 2 factors with three replications. The first factor was corn cultivar, consisting of four cultivars (Bisi 18, NK 33, DK 95 and Sukmaraga.

The relatively more significant proportion of use of organic fertilizer or manure, especially in annual horticulture, has the potential to spread weeds as a source of infestation if manure or organic fertilizer is not treated thoroughly (Bajwa *et al*., 2014). In addition to processing, organic fertilizer can affect the distribution level and the types of weeds that will grow in the yard. Research by Patel *et al*., (2018) shows that manure can reduce weed growth populations compared to other types of natural fertilizers.

Potatoes grown without mulch will increase the likelihood that weeds will grow, so weed control is necessary to prevent more significant output losses. The species and density of weeds, the competition's length, and the weeds' allelopathic release all affect yield reduction. Overall, weeds cause more crop loss than pests and illnesses combined. Even so, their losses are typically estimated since weeds' effects are only sometimes apparent. Numerous studies have revealed a negative relationship between dry weed weight and crop production (Rahman *et al*., 2017). This study aimed to identify the biodiversity of weeds in potato cultivation in Pangalengan and Cikajang sub-districts, Indonesia.

## MATERIALS AND METHODS

### Area of Study and Experimental Site

The research was conducted from December 2020 to February 2021 in potato fields in Cikajang and Pangalengan Sub-districts. Pulosari and Cikadang villages were selected as the places to conduct vegetation analysis. Five potato fields with different agro climates and agroecological conditions were selected for this research in one village.

### The Geographical Conditions of Study Sites

Observations in Pulosari village, Pangalengan Sub-district, Bandung regency found it at an approximate altitude of ±1460 m asl (meter above sea level). The altitude of the location observed is not the general requirement for necessitating the growth of Cyperus rotundus, usually found at lowlands

with 1000 m asl altitude. However, based on land characteristics, the weed prefers growing in an open place or places not exposed to direct sunlight, such as humid agricultural lands, fields, gardens, moors, or roadsides. Pangalengan Sub-district, located on a plateau or mountain area, has a cool climate, ranging from 16 °C to 25 °C. In 2020, rainfall in this area was measured to be 1.996 mm/ year with an average of 5.47 mm/day. The highest rainfall was recorded in February, measuring 11.61 mm/day, while the lowest was recorded in July, measuring 0.34 mm/ day. Also, in the year, the highest days of rain occurred in February, while the lowest days occurred in July, based on Pangalengan Local Statistics.

Cikajang Sub-district, located on a plateau or mountain area, has a cool climate, ranging from 24 ºC to 29 ºC. In 2020, rainfall in this area was measured to be 1,736 mm/year with an average of 4.83 mm/day. The highest rainfall was recorded in March, measuring 7.2 mm/day, while the lowest was recorded in July, measuring 1.9 mm/day. Also, in the year, the highest days of rain occurred in March, while the lowest days occurred in July, based on Cikajang Local Statistics.

Pangalengan and Cikajang Sub-districts are in plateaus with good soil fertility, enabling them to grow and cultivate agricultural commodities. Pangalengan Sub-district has an andisol type of soil. Its spread is limited to surrounding or near volcanoes (Hartono *et al*., 2019), while the Cikajang Sub-district has an andosol associate soil type (Randriani *et al*., 2014)komponen buah, komponen biji, dan hasil biji beras pada tanaman kopi merupakan hal penting dalam program pemuliaan dan seleksi. Model saling keterkaitan antar karakter tersebut adalah model sebab-akibat dan dapat dianalisis melalui analisis lintasan bertahap (ALB.

## Methods of Data Collection

The research used a qualitative method in the form of a weed survey and a quantitative method in identification. The researchers selected five horticultural plant areas with potatoes as produce in one village in each sub-district, with diverse agro climate and agroecological conditions. Vegetation analysis was conducted once in each sample location with plots distributed in the lower right, lower left, upper right, upper left, and center of the field for each area of the potato field with the Quadrate Sampling Technique method on a double plot, with the quadrant measurement used is 0.5 m × 0.5 m. At the time of analysis, the potato crops were aged ±30 days.

## Diversity Index (H') Analysis

Determination of the Diversity Index (H') is carried out based on the method of Shannon-Wiener with calculations using the formula (1) based on research conducted by Nolan & Callan (2006).

$$H' = -\sum_{i=1}^{s}(pi)(\ln pi) \dots\dots\dots\dots\dots (1)$$

As well as H′ = diversity index, *pi* = The sum of the important values of a species/ the sum of the important values of all species, ln = Logaritme natural.

## Community Coefficient (C) Analysis

The Community Coefficient (C) was measured using the formula by Sumekar & Widayat (2021) shown in (2).

$$C = \frac{2W}{a+b} \times 100\% \dots\dots\dots\dots\dots\dots (2)$$

As well as C = Community Coefficient, W = the sum of the two lowest quantities for species from each community, a = the sum of all the quantities in the first community, b = the sum of all the quantities in the second community.

## Summed Dominance Ratio (SDR) and Important Value Index (IVI) Analysis

Summed dominance ratio value is calculated using formula (3) & (4) based on Satriawan & Fuady (2019).

$$SDR = \frac{Importance\ value\ index\ (IVI)}{Number\ of\ spices} \dots\dots\dots\dots\dots\dots (3)$$

IVI = Relative Density + Relative Frequency + Relative Dominance.....(4)

## RESULTS AND DISCUSSION

Results revealed the presence of 14 weed species in Fields 1-5 at Pangalengan Sub-district, consisting of four species of grassy weeds (*Cynodon dactylon, Eleusine indica, Paspalum conjugatum, Digitaria sanguinalis*), two species of sedges (*Cyperus rotundus, Erigeron sumatrensis retz)*, and eight species of broadleaf weeds (*Portulaca oleracea, Galinsoga parviflora, Richardia brasiliensis, Drymaria villosa, Erechtites sp., Alternanthera sessilis, Calopogonium mucunoides Desv, Alternanthera philoxeroides).* In this list, the dominant weeds in Pangalengan fields were *Cyperus rotundus, Cynodon dactylon, Eleusine indica,* and *Galinsoga parviflora* (Table 1).

In contrast to Pangalengan, the data in Table 1 shows that there are 15 species of weeds found in Cikajang. Two types of grass weeds (*Cynodon dactylon, Eleusine indica*) were recorded, two types of reed grass (*Cyperus rotundus, Oxalis latifolia*), and 11 types of broadleaf weeds (*Portulaca oleracea*, *Artemisia vulgaris* L, *Galinsoga parviflora*, *Alternanthera sessilis*, *Erechtites sp.*, *Amaranthus spinosus* L, *Celosia argentea*, *Drymaria villosa*, *Ageratum conyzoides, Hydrocotyle leucocephala*, and *Richardia brasiliensis*). The dominant weeds in

**Table 1. Average of Importance Value Index, Summed Dominance Ratio, Species Diversity Index, and Dry Weight of Weed in Pangalengan and Cikajang sub-districts**

| No. | Name of Species | Importance Value Index (%) | | Summed dominance ratio (%) | | Species Diversity Index (H') | | Weight Dry Weeds (g/0,25 m$^2$) | |
|---|---|---|---|---|---|---|---|---|---|
| | | CKJ | PNG | CKJ | PNG | CKJ | PNG | CKJ | PNG |
| 1 | *Ageratum conyzoides* | 5.13 | - | 0.34 | - | 0.019 | - | 0.02 | - |
| 2 | *Alternanthera philoxeroides* | - | 155.99 | - | 10.4 | - | 0.235 | - | 0.92 |
| 3 | *Alternanthera sessilis* | 262.09 | 101.05 | 17.47 | 6.74 | 0.305 | 0.182 | 4.04 | 0.32 |
| 4 | *Amaranthus spinosus* L | 20.19 | - | 1.35 | - | 0.058 | - | 0.06 | - |
| 5 | *Artemisia vulgaris* L | 37.82 | - | 2.52 | - | 0.093 | - | 0.34 | - |
| 6 | *Calopogonium mucunoides* Desv | - | 137.56 | - | 9.17 | - | 0.219 | - | 0.4 |
| 7 | *Celosia argentea* | 9.13 | - | 0.61 | - | 0.031 | - | 0.02 | - |
| 8 | *Cynodon dactylon* | 114.53 | 223.44 | 7.64 | 14.9 | 0.196 | 0.284 | 2.58 | 4.86 |
| 9 | *Cyperus rotundus* | 42.66 | 281.94 | 2.84 | 18.8 | 0.101 | 0.314 | 1.24 | 4.84 |
| 10 | *Digitaria sanguinalis* | - | 13.66 | - | 0.91 | - | 0.043 | - | 0.22 |
| 11 | *Drymaria villosa* | 101.17 | 75.23 | 6.74 | 5.02 | 0.182 | 0.150 | 0.38 | 0.78 |
| 12 | *Eleusine indica* | 337.55 | 212.66 | 22.5 | 14.18 | 0.336 | 0.277 | 6.82 | 2.42 |
| 13 | *Erechtites* sp. | 89.56 | 5.16 | 5.97 | 0.34 | 0.168 | 0.020 | 1.78 | 0.1 |
| 14 | *Erigeron sumatrensis* retz. | - | 11.93 | - | 0.8 | - | 0.038 | - | 0.1 |
| 15 | *Galinsoga parviflora* | 311.25 | 227.95 | 20.75 | 15.2 | 0.326 | 0.286 | 4.66 | 2.56 |
| 16 | *Hydrocotyle leucocephala* | 5.13 | - | 0.34 | - | 0.019 | - | 0.02 | - |
| 17 | *Oxalis latifolia* | 112.98 | - | 7.53 | - | 0.195 | - | 0.42 | - |
| 18 | *Paspalum conjugatum* | - | 6.82 | - | 0.45 | - | 0.025 | - | 0.04 |
| 19 | *Portulaca oleracea* | 34.12 | 40.49 | 2.27 | 2.7 | 0.086 | 0.098 | 0.2 | 0.74 |
| 20 | *Richardia brasiliensis* | 16.69 | 6.12 | 1.11 | 0.41 | 0.050 | 0.022 | 0.08 | 0.08 |
| Total value | | 1500 | 1500 | 100.0 | 100.0 | 2.166 | 2.193 | 22.660 | 18.380 |

Note : CKJ : Cikajang; PNG : Pangalengan

Cikajang were *Alternanthera sessilis, Galinsoga parviflora, Drymaria villosa*, and *Eleusine indica*.

## Summed Dominance Ratio (SDR) and Important Value Index (IVI)

*Cyperus rotundus* (18.80 %) was the weed with the highest SDR in Pangalengan. It is included in *the Cyperaceae* family (sedges). *Cyperus rotundus* is a C4 weed, marked by high photosynthetic efficiency, which causes it to be more bothersome than C3 weeds (Baloch, 2015). The damaging effects of *Cyperus rotundus* on eco-nomically-important vegetable produce and crops are significantly visible. The weed works differently in different crops, and therefore an interspecific solution between *Cyperus rotundus* and different vegetables shows the negative impact of the weed on the vegetable yield. For instance, an 89% decrease in onion yields, 62% decrease in okra yields, 39-50% decrease in carrot yields, 43% decrease in cucumber yields, and 35% decrease in cabbage yields are reported when grown on a field full of *Cyperus rotundus* (Du *et al*., 2019)which infests peanut fields in south China and causes considerable peanut yield losses. Information on the interference of purple nutsedge on peanut and its economic threshold (ET. In addition to the damage caused, *Cyperus rotundus* has adaptive characteristics where this weed can grow strong and fertile in tropical and subtropical agricultural land (Peerzada, 2017; Sutomo & Fardila, 2015).

The high SDR value in *Cyperus rotundus* is because this weed has broad growing power with fibrous roots that can grow to a soil depth of 40 cm and reproduce horizontally with large areas with rhizome organs (Baloch, 2015).

Various attempts have been made to deal with this weed either by crop rotation with bean plants to tillage either manually using a hoe or using a machine due to failure to remove weeds to the root tubers where these organs can last up to two years in the soil as long as moisture conditions are met. In addition, different tuber sizes correlate with different dormancy levels, the most critical adaptive factor that allows *Cyperus rotundus* to cope with a less conducive environment (Baloch, 2015; Ravisankar *et al*., 2017). *Under favorable conditions, a plant originating from a single tuber can multiply into 100 or more tubers in approximately 100 days* (Baloch, 2015; Ravisankar *et al*., 2017).

Unlike the Pangalengan area, *Eleuisine indica* (22.50 %) has the highest SDR value in Cikajang. It is included in the *Eleusine* genus of the *Poaceae* family. It is a seasonal grass with strap-shaped leaves (Zakri *et al*., 2021). It forms a dense, slightly widened, low clump since it grows in clumps and has a fibrous rooting system. Its leaves are green and have silvery color on their base, with an elongated shape and folded strands (Boyd *et al*., 2020). In the leaf, surface fluffs are nearly not found. The weed has panicles that appear serrated. The seeds are arranged like bunches on flower stalks. In each panicle, there exist 3-7 bunches at the end of the stem with more than 50,000 seeds (Breeden *et al*., 2017).

The planting pattern in Cikajang uses rotation with carrots. Here, tillage is still performed manually. Even though plant rotation is conducted, the weed will remain flowering each year, with each plant producing up to 140,000 seeds each season (Lee & Ngim, 2000; Nambela, 2019)this weed could be easily controlled by glyphosate at 720 g isopropylamine salt ha-1. In late 1997, a fruit grower in Teluk Intan, Perak, Malaysia, reported that glyphosate failed to give adequate control of E indica in his four-year-old orchard. In response to the grower's feedback, an on-site field trial was initiated to evaluate the efficacy of glyphosate at 720 to 5760 g salt ha-1 for control of the

weed. Results from this trial confirmed the grower's observation. Glyphosate at 5760 g salt ha-1 gave only about 25% control of E indica ('Teluk Intan' biotype.

In this experiment, a direct test on the field was conducted in the form of soil observation. It was found that the average pH was 5.92 with 55% humidity, therefore classifying the soil as suitable for the classification of tools used for the potato crop.

Potato fields in Cikajang have humid characteristics due to low temperatures. It correlates positively with the weed's growth requirement, in which it can grow on a humid or not too dry and open or a little shaded land. Garut regency's rainfall, amounting to more than 1000 mm annually, includes this area in the C category, according to Schmidt-Ferguson, or dampish. The weed's area of spread, which covers the land with 0-1600 m asl altitudes, is suitable for the location of Cikandang village, Cikajang Sub-district, Garut regency, which has an approximate altitude of ±1380 m asl (Breeden *et al*., 2017).

Weed control on potato crop fields in Pangalengan and Cikajang is performed using mechanical and chemical means. Mechanical control is performed ±30 days after planting, while chemical control uses Roundup™ herbicides. *Roundups*™ is a herbicide that uses glyphosate-active ingredients often used globally. Glyphosate (N-phosphonomethyl-glycine) controls weed and perennial grass in various farming crops, such as rice, corn, and soy (Baer & Marcel, 2014; Kanissery *et al*., 2019). It inhibits plant metabolism, especially in synthesizing amino acids (Kőmíves & Schröder, 2016). The plant will wither, turn yellow, and die some days after spraying. Glyphosate herbicide contains chemical ingredients that make it stay on the leaves, enabling it to move from the plant surface to the plant cells.

In general, broadleaf weeds were the most found type of weeds. It was high in population and quite dominant. *Asteraceae* is included in annual, widely scattered weed. Weeds belonging to this family are considered malignant, therefore explaining their often dominance over other wild plants in one land (Araújo *et al*., 2021).

Broadleaf weeds are plants that play a vital role in the stability of the ecosystem in an area, one of which is to prevent soil erosion in an area (Lenka *et al*., 2017). Broadleaf weeds can also grow well in a tropical continent with high-intensity sunlight, which is most relevant with open potato lands since sunlight is the primary energy source in helping photosynthesis, a food production process for the plant (Khan *et al*., 2020)"ISSN": "21680485","abstract":"Biodegradable mulches are considered a promising alternative to polyethylene-based, nonbiodegradable mulch for sustainable agriculture. In the present study, a bioactive 2-methyl-4-cholorophenoxyacetic acid/poly(3-hydroxybutyrate-co-3-hydroxyvalerate.

Types with high relative frequency values also have a high density and tend to occupy a wide area. Generally, plants with the highest importance value index (IVI) have better-adapting power, competition power, and reproduction capability than other plants in a particular land (Didita *et al*., 2010; Ismail *et al*., 2017).

## Species Diversity Index (H')

This research used Shannon-Wiever's Species Diversity Index (H') value, which employed criteria in further meaning interpretation. H' value usually approximates from 0-7. H' < 1 is considered very low, H' > 1-2 is considered low, H' < 2-3 is considered medium, H' > 3-4 is considered high, and H' > 4 is considered very high.

Data in Table 1 show that Species Diversity Index (H') value in Pangalengan amounted to 2.19, therefore considered medium. Species diversity consists of two components: the number of species in a community, usually called species wealth, and species similarity. The similarity here refers to the abundance of individuals of one type. Data in Table 1 show that Species Diversity Index (H') value in Cikajang was found to amount to 2.16, therefore considered medium, with the same components of species diversity: the species wealth and similarity.

Several factors can influence the type and diversity of weeds in the land, including soil type and crown condition. Cultural control practices will influence the degrees of competition between weeds to cultivated plants. It is further stated that the density of weeds growing in agricultural lands varies according to the season. During the rainy season, water reserves are plenty and, in turn, increase weed population, and vice versa (Bir *et al*., 2014).

Species diversity indices of the two sub-districts are included in the medium category, following the reference index by Barbour *et al*. (1987). This condition follows the research of Furtak & Gałązka (2019) and Haq *et al*. (2022), stating that a specific range of environment also has specific edaphic parameters, meaning that soil nutrients in the location of the study are not distributed so that even distribution of species living on it is not possible. Based on the observation and analysis results, it was apparent that components of species wealth or types of species living in the location of the study are pretty high.

## Community Coefficient Index (C)

The index of the coefficient of community similarity ranges from 0 to 100%. The nearer to 100% the number, the higher the stand condition is compared. From the community similarity value (IS) obtained, the coefficient of community dissimilarity (ID) can be calculated using the formula of 100 – IS. Density, biomass, crown placement, or IVI can be used to calculate IS.

Table 3 shows the weed dominance index (C) in the Pangalengan and Cikajang Sub-districts, which amounts to 54.64% or can be said to have a high degree of difference. Based on the benchmark value in Table 2, the value of the weed dominance index is included in the category level of Similar in the level of community similarity. The existence of high difference levels of weeds is because species growing in Pangalengan did not grow in Cikajang.

Species that show dominance in a plant community state the level of species domination (Avolio *et al*., 2019). Dominance states the main plant species that influence and control the community. The dominance of a plant species is shown through its large population, the larger diameter of its stem, and dominant growth.

**Table 2. Community Coefficient Benchmark Value**

| Benchmark Value | Information |
|---|---|
| 91%-100% | There is a very high community similarity |
| 71%-90% | There are similarities in the same community |
| 56%-70% | Similar level of community similarity |
| 45%-55% | Low level of similarity or different |
| <45% | Very different degree of similarity |

**Table 3. Coefficient Community value in Pangalengan and Cikajang sub-districts**

| Compound | Value |
|---|---|
| W | 54.64 |
| A (Cikajang) | 100 |
| B (Padalarang) | 100 |
| C (%) | 54.64 |

Note : W: The sum of the two lowest quantities for the type of each community, a : The sum of all the quantities in the first community, b : The sum of all the quantities in the second community, C : Community Coefficient (%)

According to Kaur *et al*. (2018), weeds can reproduce and survive more than the main plant because they have special characteristics, including having quite a rapid pace of reproduction both vegetatively and generatively.

## Dry Weight of Weed

Data in Table 1 show that the weed species having the total weight in all observed fields in Pangalengan is *Cynodon dactylon,* while those in Cikajang are *Eleusine indica.* Total dry weight in all observed fields amounted to 18.38 g, while those in Cikajang amounted to 22.66 g.

Research results show that results in Pangalengan and Cikajang Sub-districts were found to have little difference since two control mechanisms are used in the two places: mechanical and chemical control. Both areas used Roundup™ herbicide, a type of pre-growth herbicide. Spraying was performed before tillage in the initial stage of soil preparation. This condition conforms to Matloob *et al*. (2020) and Singh *et al*. (2022) who stated that weeds interact with plants through competition to obtain one or more limited growth factors such as light, nutrients, and water. This condition also fits to statement by Hussain *et al*. (2018)the efficacy of mechanical weed control has been reevaluated. Tillage (used for soil preparation for planting that mechanical control of weeds can suppress weed growth by damaging part of the plant until they die or until their growth is inhibited.

Weed growth is a complex combination, which is a process of growth leading to plant dry weight accumulation. This condition is because the weed's vegetative growth greatly influences dry weight. If the vegetative growth rises, then the dry weight rises also. There are many factors influencing weed closing and dry weight on cultivation lands. Intensive land use will make weed closing and dry weight rise, but both will drop with plowing or flipping soil over.

Weeding activities can reduce competition between weeds and the main crop. Reducing the number of weeds spread in one area plot can reduce the intensity of competition for nutrients, water, and light to provide growing space and better facilities for the main crops for growth and development (Gosh *et al*., 2021; Swanton *et al*., 2015).

The dry weight of weeds tends to increase again during harvest. This condition happens when the wedding is not performed. In succeeding development, weed develops fast and starts showing active growth, so the weed population reflects the more significant weed density (Baloch, 2015).

## CONCLUSION

The results of the vegetative analysis revealed that the populations of weeds on potato plants in the districts of Pangalengan and Cikajang were distinct. Pangalengan has 14 varieties of weeds, including four types of grasses, two types of grasses, and eight types of broadleaf weeds. In Cikajang, there are 15 types of weeds, including two types of grasses, two types of weeds, and two types of weeds. *Cyperus rotundus* and *Eleusine indica* obtained the region's highest Summed Dominance Ratio (SDR) values. The species diversity index (H') values of 2.16 and 2.19, which fall within the medium category, and the community coefficient index value (C) of 54.64% also reveal differences in biodiversity. Due to variations in land conditions, this number has a large margin of error (micro-climate). The anticipated outcome of this research is that it can serve as a reference for applying methods and chemicals for effective and efficient weed control. With the information obtained from identifying the spread of weed development, it is intended

that the methods and materials for weed control will be applied with precision.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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# KUFRI LOHIT: A NEW RED SKIN POTATO VARIETY

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**ABSTRACT: Kufri Lohit is a red skin, medium maturing, main season, high yielding table potato variety recommended for cultivation in North-Indian plains (Eastern & Central plains). It can also successfully be grown in northern plains to meet the seed potato demands of regions that prefer red skin tubers. It is a clonal selection of a cross between Kufri Kanchan and Kufri Khyati. Its plants are medium tall and vigorous having field resistance to late blight. It produces attractive red coloured, ovoid tubers with shallow eyes, cream flesh, and mealy texture. This variety possesses approximately 18% tuber dry matter content and has very good keeping quality. It is responsive to crop nutrition and yields 36–38 t/ha total tuber yield under optimum crop management.**

**KEYWORDS:** Kufri Lohit, variety, table potato, red skin, high yield, late blight, keeping quality, North-Indian plains.

## INTRODUCTION

Red skinned potatoes are preferred by consumers especially in the eastern part of India (eastern Uttar Pradesh, Bihar, Jharkhand, West Bengal, and Orissa) and in Jammu & Kashmir. Though white/yellow skinned or flesh potatoes are the common preference in other parts of the country, however, preference for red skin potatoes is increasing due to the migrant population from eastern states who has a liking for red skin tubers. Market supply chain dynamics also influence potato growers in different regions for raising red skin varieties. As in district Kannauj (UP), farmers are cultivating red skin potatoes to cater to the demand of locals and markets of the neighbouring country Nepal. Similarly, in district Bareilly (UP), the local cultivar Bareilly Red is highly preferred among the zone's consumers because its dark red tubers have variegated flesh colour and waxy texture (Luthra *et al.*, 2015a). Some local potato varieties having purple black or purple skin, although having low yield potential, are grown and consumed in several pockets of North-Western hills and the North-Eastern region. These locally adapted varieties remain popular due to the slow rate of degeneration and unique taste liked by the local populace (Luthra *et al.,* 2015b). As consumers are also becoming aware of their health and the better nutritive value of food, so coloured potatoes shall also be preferred by them due to their higher antioxidant potential (Luthra *et al.*, 2018). CPRI has developed eight indigenous varieties with red skin and white or white-cream flesh colour and one purple skinned variety Kufri Neelkanth with yellow flesh colour (Luthra *et al.*, 2020b). Efforts are continuing to develop better genotypes in this segment for potato growers and consumers to meet the ever-increasing demand. Work in this direction has led to the development of a new high-yielding, late blight resistant potato variety named Kufri Lohit. Its tubers are red skinned and its flesh colour is cream. This variety possesses very good keeping quality and taste. This will provide an opportunity for farmers to get higher farm profits and wider choice for consumers in their food basket.

## BACKGROUND

Advanced clone MS/11-664 released as table purpose potato variety Kufri Lohit

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was bred and selected at Modipuram (Uttar Pradesh), a regional station of Central Potato Research Institute, Shimla (Himachal Pradesh) following breeding protocols (Luthra *et al*., 2020a). The clone was derived from a cross between Kufri Kanchan × Kufri Khyati made in 2009 at Kufri (Himachal Pradesh). Female parent Kufri Kanchan is an indigenous medium maturing variety that was released in 1999 for north Bengal hills and Sikkim. It produces red oblong tubers with fleet eyes and cream flesh, moderate resistance to late blight, and immunity to warts. Male parent Kufri Khyati is a medium maturing early bulking indigenous variety released in 2008 for North-Indian plains. It produces white-cream ovoid tubers with shallow eyes and creamy flesh and is moderately resistant to late blight. The pedigree of Kufri Lohit is described in Figure 1. The clone was in the seedling stage (2010-11), five-hill plots (2011-12), 30 hill-plots (2012-13), and multiple row trials (2013-14). It was evaluated in one preliminary (2014-15) and two confirmatory yield trials (2015-16 and 2016-17) at Modipuram. Advanced clone MS/11-664 was introduced in the All India Coordinated Research Project on Potato (AICRP on Potato) in 2017 for multi-location evaluation across the country.

Clone MS/11-664 was evaluated in multi-location replicated trials under AICRP on Potato during 2018-19 and 2019-20 at 14 locations, and during 2020-21 at 15 locations in North-Indian plains comprising northern, central, and eastern regions. It showed wider adaptability and higher yield than the controls. The data was analyzed following standard statistical procedures using the online statistical software OPSTAT, CCS HAU, Hisar, Haryana (Sheoran *et al,* 1998). Based on its performance, the clone was recommended for release as table purpose potato variety for North-Indian plains (Eastern & Central plains) in the 39th Group Meeting of AICRP on Potato held during September 27-29, 2021 through virtual mode. Advanced clone MS/11-664 has been released and notified as variety in the name of Kufri Lohit by the Central Sub-Committee on Crop Standards Notification and Release of Varieties for Horticultural Crops, Ministry of Agriculture, Department of Agriculture and Co-operation, Government of India, New Delhi during its 30th meeting on 04.05.2023.

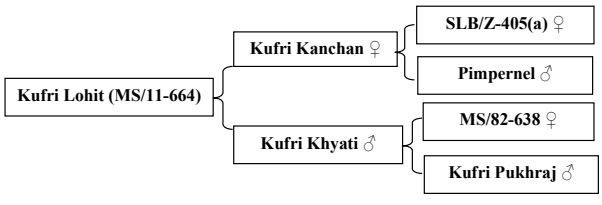



*Fig. 1. Pedigree of Kufri Lohit*

## VARIETAL DESCRIPTION

**Plants:** Morphological characteristics of the variety Kufri Lohit (leaf, flower, sprout, and tuber) have been depicted in Figure 2.

***Plant:*** Medium, plant canopy semi-compact, stem medium thick, predominantly green,




*Fig. 2. Morphological characteristics of Kufri Lohit: Leaf, flower, sprout and tuber*

secondary stem colour red brown throughout lightly scattered, wings highly developed and straight.

***Foliage:*** Grey green, leaves intermediate, leaf width broad, leaflets ovate lanceolate, leaflet coalescence absent, rachis coloured, midrib coloured.

### Inflorescence

***Flowering:*** Medium, inflorescence large, floral stalk medium and coloured, pedicle articulation clearly visible in floral stalk and located above middle, calyx light red brown, corolla red violet, corolla shape semi-stellate, anther yellow, anther cone normally developed, stylar length longer than stamen column and stigma bi-lobed.

### Tubers

***Size:*** Medium to large, 8-9 tuber per plant; ***Shape:*** Ovoid; ***Skin:*** Smooth and red; ***Eyes:*** Shallow, predominantly apical; ***Eyebrows:*** Normal; ***Flesh:*** Cream with mealy texture.

### Sprout

Red purple, spherical, pubescence at sprout base is weak, sprout tip closed, length of apical sprout is medium (2-5 cm).

## YIELD PERFORMANCE

### Station trials

In station trials at Modipuram during 2014-15, 2015-16, and 2016-17, advanced clone MS/11-664 (32.24 t/ha) yielded 16 and 15% higher total tuber yield over Kufri Lalit (27.91 t/ha) and Kufri Lalima (28.07 t/ha) at 75 days (**Table 1**). This clone produced nearly 95% marketable tubers as compared to Kufri Lalit and Kufri Lalima (91%). Clone MS/11-664 (42.76 t/ha) yielded 10 and 20% higher total tuber yield over Kufri Lalit (38.75 t/ha) and Kufri Lalima (35.65 t/ha) at 90 days. Its marketable tuber yield (96%) was slightly superior to Kufri Lalit (95%) and Kufri Lalima (94%).

### Multi-location testing

Replicated multi-location yield trials along with controls were conducted under AICRP on Potato during 2018-19 and 2019-20 at 14 locations (**Table 2**) and during 2020-21 at 15 locations (**Table 3**) in North-Indian plains comprising its northern, central, and eastern parts.

### Replicated yield trials (2018-19 & 2019-20)

**Crop duration (75 days):** Advanced clone MS/11-664 (32.14 t/ha) had 5 and 11 % higher

**Table 1. Performance of advanced clone MS/11-664 at Modipuram during 2014-2017**

| Genotypes | Total tuber yield (t/ha) | | | | | | | | Yield increase (%) over controls | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014-15 | | 2015-16 | | 2016-17 | | Mean | | | |
| | 75 *DAP | 90 DAP | 75 DAP | 90 DAP | 75 DAP | 90 DAP | 75 DAP | 90 DAP | 75 DAP | 90 DAP |
| MS/11-664 | 26.52 | 37.63 | 34.71 | 43.79 | 35.49 | 46.85 | 32.24 | 42.76 | | |
| Kufri Lalit | 26.30 | 32.79 | 29.86 | 43.73 | 27.58 | 39.73 | 27.91 | 38.75 | 15.51 | 10.35 |
| Kufri Lalima | 23.73 | 29.99 | 30.62 | 40.15 | 29.84 | 36.80 | 28.07 | 35.65 | 14.86 | 19.94 |
| CD (0.05) | 2.00 | 2.34 | 2.65 | 1.84 | 2.09 | 1.80 | 2.18 | 1.59 | | |
| | Marketable tuber yield (t/ha) | | | | | | | | | |
| MS/11-664 | 24.70 | 35.55 | 33.54 | 42.51 | 33.49 | 45.00 | 30.58 | 41.02 | | |
| Kufri Lalit | 23.31 | 30.83 | 27.41 | 41.62 | 25.24 | 38.04 | 25.32 | 36.83 | 20.77 | 11.38 |
| Kufri Lalima | 21.29 | 27.86 | 28.02 | 37.65 | 27.67 | 34.65 | 25.66 | 33.39 | 19.17 | 22.85 |
| CD (0.05) | 2.13 | 2.16 | 2.24 | 1.53 | 1.55 | 1.64 | 1.86 | 1.45 | | |

*DAP: Days after planting

**Table 2. Performance of advanced clone MS/11-664 in AICRP on Potato replicated yield trials pooled over 2018-19 and 2019-20 at 75 and 90 days**

| Regions | Locations | Total tuber yield (t/ha) at 75 days | | | Total tuber yield (t/ha) at 90 days | | |
|---|---|---|---|---|---|---|---|
| | | MS/11-664 | Kufri Lalit | Kufri Lalima | MS/11-664 | Kufri Lalit | Kufri Lalima |
| Northern plains | Hisar | 33.02 | 35.29 | 32.42 | 39.03 | 42.08 | 38.76 |
| | Jalandhar | 32.75 | 33.61 | 28.78 | 43.51 | 40.14 | 35.50 |
| | Modipuram | 37.70 | 31.97 | 33.23 | 53.23 | 48.30 | 45.83 |
| | Pantnagar | 25.08 | 22.16 | 21.50 | 28.16 | 25.31 | 27.87 |
| | Mean | 32.14 | 30.76 | 28.98 | 40.98 | 38.96 | 36.99 |
| | % Yield ± | | 4.49 | 10.89 | | 5.20 | 10.79 |
| Central plains | Deesa | 46.29 | 40.48 | 44.69 | 56.91 | 54.61 | 54.95 |
| | Gwalior | 41.31 | 35.64 | 34.61 | 44.27 | 39.55 | 39.41 |
| | Kanpur | 40.19 | 32.68 | 28.80 | 45.06 | 35.75 | 31.41 |
| | *Kota | 26.16 | 21.21 | 23.24 | 37.30 | 25.42 | 31.67 |
| | Raipur | 33.27 | 26.06 | 31.34 | 39.85 | 31.80 | 37.58 |
| | Mean | 37.44 | 31.21 | 32.54 | 44.68 | 37.43 | 39.00 |
| | % Yield ± | | 19.96 | 15.08 | | 19.38 | 14.55 |
| Eastern plains | Bhubaneshwar | 21.71 | 15.18 | 15.42 | 24.56 | 18.93 | 16.91 |
| | Dholi | 21.65 | 19.55 | 24.68 | 24.07 | 22.17 | 22.29 |
| | Faizabad | 29.56 | 28.46 | 23.11 | 37.33 | 35.71 | 32.03 |
| | Kalyani | 26.25 | 20.71 | 23.01 | 32.38 | 32.59 | 31.01 |
| | Patna | 22.80 | 25.85 | 22.54 | 30.87 | 27.07 | 24.80 |
| | Mean | 24.39 | 21.95 | 21.75 | 29.84 | 27.29 | 25.41 |
| | % Yield ± | | 11.13 | 12.15 | | 9.34 | 17.45 |
| Overall mean | | 31.27 | 27.78 | 27.67 | 38.32 | 34.25 | 33.57 |
| % Yield ± | | | 12.57 | 13.00 | | 11.91 | 14.15 |
| CD (0.05) | | Genotypes: 0.96, Genotype x location: 2.59 | | | Genotypes: 0.70, Genotype x location: 2.52 | | |

*Kota: Kufri Pukhraj/ Kufri Khyati in place of Kufri Lalit/ Kufri Lalima

total tuber yield over the controls Kufri Lalit (30.76 t/ha) and Kufri Lalima (28.98 t/ha), respectively in northern plains. Performance of MS/11-664 (37.44 t/ha) was 20 and 15% superior to Kufri Lalit (31.21 t/ha) and Kufri Lalima (32.54 t/ha) in central plains. In eastern plains, MS/11-664 (24.39 t/ha) outyielded the control Kufri Lalit (21.95 t/ha) and Kufri Lalima (21.75 t/ha) by a margin of 11% and 12% respectively (**Table 2**). Overall, MS/11-664 (31.27 t/ha) produced 13% higher total tuber yield than controls Kufri Lalit (27.78 t/ha) and Kufri Lalima (27.67 t/ha). This clone produced nearly 90% marketable tuber yield, which was at par with Kufri Lalit (90%) and Kufri Lalima (88%).

**Crop duration (90 days):** Advanced clone MS/11-664 (40.98 t/ha) recorded 5 and 11 % higher total tuber productivity over the controls Kufri Lalit (38.96 t/ha) and Kufri Lalima (36.99 t/ha) in northern plains. In central plains, clone MS/11-664 (44.68 t/ha) attained 19 and 15% higher yields as compared to Kufri Lalit (37.43 t/ha) and Kufri Lalima (39.00 t/ha). Whereas in eastern plains, MS/11-664 (29.84 t/ha) had 9% and 17% more total tuber productivity compared to the control Kufri Lalit (27.29 t/ha) and

**Table 3. Performance of advanced clone MS/11-664 in AICRP on Potato replicated yield trials (2020-21) at 75 and 90 days**

| Regions | Locations | Total tuber yield (t/ha) at 75 days | | | | Total tuber yield (t/ha) at 90 days | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS/11-664 | Kufri Manik | Kufri Lalit | Kufri Lalima | MS/11-664 | Kufri Manik | Kufri Lalit | Kufri Lalima |
| Northern plains | Hisar | 37.67 | 32.99 | 34.06 | 32.88 | 48.24 | 43.64 | 46.42 | 39.71 |
| | Jalandhar | 39.24 | 37.76 | 43.40 | 41.49 | 54.69 | 45.83 | 51.04 | 50.87 |
| | Modipuram | 31.64 | 30.79 | 27.92 | 29.19 | 48.09 | 38.32 | 43.94 | 38.12 |
| | Pantnagar | 22.51 | - | 23.11 | 23.87 | 27.34 | - | 27.88 | 26.80 |
| | Mean | 32.77 | 33.85 | 32.12 | 31.86 | 44.59 | 42.60 | 42.32 | 38.88 |
| | % Yield ± | | -3.20 | 2.00 | 2.85 | | 4.68 | 5.36 | 14.70 |
| Central plains | Chhindwara | 34.33 | 25.78 | 34.55 | 33.77 | 39.60 | 33.23 | 41.09 | 38.80 |
| | Deesa | 46.09 | - | 44.90 | 40.71 | 51.25 | - | 51.43 | 42.86 |
| | Gwalior | 29.16 | - | 31.17 | 23.20 | 42.59 | - | 38.50 | 28.53 |
| | Kanpur | 34.28 | 28.58 | 23.96 | 23.65 | 45.70 | 27.50 | 27.47 | 34.31 |
| | Kota | - | - | - | - | 52.37 | - | 40.79 | 23.65 |
| | Raipur | 27.27 | | 35.40 | 28.26 | 29.13 | - | 42.44 | 31.36 |
| | Mean | 34.23 | 27.18 | 34.00 | 29.92 | 43.44 | 30.37 | 40.29 | 33.25 |
| | % Yield ± | | 25.92 | 0.68 | 14.40 | | 43.06 | 7.83 | 30.64 |
| Eastern plains | Bhubaneshwar | 12.16 | 8.45 | 10.38 | 10.82 | 18.43 | 13.72 | 12.25 | 16.71 |
| | Dholi | 31.65 | 29.35 | 31.48 | 30.19 | 34.32 | 33.41 | 32.97 | 32.11 |
| | Faizabad | 32.04 | 33.48 | 33.08 | 25.97 | 34.19 | 37.52 | 36.05 | 35.02 |
| | Kalyani | 27.68 | | 26.77 | 27.47 | 35.63 | | 27.36 | 30.24 |
| | Patna | 29.68 | 24.78 | 23.90 | 18.92 | 30.70 | 27.79 | 27.43 | 21.84 |
| | Mean | 26.64 | 24.02 | 25.12 | 22.67 | 30.65 | 28.11 | 27.21 | 27.18 |
| | % Yield ± | | 10.94 | 6.05 | 17.50 | | 9.05 | 12.65 | 12.76 |
| Overall mean | | 31.10 | 28.00 | 30.29 | 27.89 | 39.48 | 33.44 | 36.47 | 32.73 |
| % Yield ± | | | 11.09 | 2.67 | 11.53 | | 18.08 | 8.26 | 20.64 |
| CD (0.05): | | Genotypes: 1.13, Genotype x location: 4.50 | | | | Genotypes: 0.92, Genotype x location: 3.57 | | | |

Kufri Lalima (25.41 t/ha). On an overall basis, MS/11-664 (38.32 t/ha) recorded 12 and 14% higher total tuber yield than the controls Kufri Lalit (34.25 t/ha) and Kufri Lalima (33.57 t/ha), respectively (**Table 2**). This clone had nearly 92% marketable tuber yield remaining statistically at par with Kufri Lalit (92%) and Kufri Lalima (91%).

## Replicated yield trials (2020-21)

**Crop duration (75 days):** Advanced clone MS/11-664 (32.77 t/ha) attained 2 and 3% higher total tuber yield over Kufri Lalit (32.12 t/ha) and Kufri Lalima (31.86 t/ha) in northern plains. Performance of MS/11-664 (34.23 t/ha) was 26, 1, 14% better than Kufri Manik (27.18 t/ha), Kufri Lalit (34 t/ha), and Kufri Lalima (29.92 t/ha), respectively in central plains. In eastern plains, MS/11-664 (26.64 t/ha) out yielded the controls Kufri Manik (24.02 t/ha), Kufri Lalit (25.12 t/ha) and Kufri Lalima (22.67 t/ha) by 11, 6 and 18% respectively (**Table 3**). Overall, MS/11-664 (31.10 t/ha) observed 11, 3, and 12% higher total tuber yield than the controls Kufri Manik (28.00 t/ha), Kufri Lalit (30.29 t/ha) and Kufri Lalima (27.89 t/ha), respectively. Advanced clone MS/11-664 recorded nearly

88% marketable tuber yield comparable to cv. Kufri Manik (88%), Kufri Lalit (91%) and Kufri Lalima (92%).

**Crop duration (90 days):** Advanced clone MS/11-664 (44.59 t/ha) produced 5, 5, and 15% higher total tuber yield over the controls Kufri Manik (42.60 t/ha), Kufri Lalit (42.32 t/ha) and Kufri Lalima (38.88 t/ha), respectively in northern plains. In central plains, its performance (43.44 t/ha) was 43, 8, 31% superior to Kufri Manik (30.37 t/ha), Kufri Lalit (40.29 t/ha), and Kufri Lalima (33.25 t/ha). Advanced clone MS/11-664 (30.65 t/ha) had 9, 13 and 13% better tuber yields in eastern plains when compared with the controls Kufri Manik (28.11 t/ha), Kufri Lalit (27.21 t/ha) and Kufri Lalima (27.18 t/ha), respectively (**Table 3**). On an overall basis, MS/11-664 (39.48 t/ha) produced 18, 8 and 21% high total tuber yield than controls Kufri Manik (33.44 t/ha), Kufri Lalit (36.47 t/ha) and Kufri Lalima (32.73 t/ha). This clone had nearly 91% marketable tuber yield, which was at par with Kufri Manik (91%), Kufri Lalit (91%), and Kufri Lalima (93%).

## Overall performance of advanced clone MS/11-664 in AICRP on Potato trials

**Crop duration (75 days):** Total tuber yield of this clone (32.45 t/ha) was 3 and 7 % higher over Kufri Lalit (31.44 t/ha) and Kufri Lalima (30.42 t/ha) in the northern plains. Performance of MS/11-664 (34.90 t/ha) was significantly higher by 28, 10, and 13% as compared to Kufri Manik (27.18 t/ha), Kufri Lalit (31.82 t/ha) and Kufri Lalima (30.77 t/ha) respectively in central plains. Whereas in eastern plains, MS/11-664 (25.52 t/ha) out yielded the control Kufri Manik (24.02 t/ha), Kufri Lalit (23.54 t/ha), and Kufri Lalima (22.21 t/ha) by a margin of 6, 8 and 15% respectively (**Table 4**). Overall, MS/11-664 (31.12 t/ha) recorded 11, 7, and 12% higher total tuber yield than the controls Kufri Manik (28.00 t/ha), Kufri Lalit (28.96 t/ha) and Kufri Lalima (27.83 t/ha), respectively. This advanced clone attained nearly 89% marketable tuber yield remaining at par with all the controls Kufri Manik (88%), Kufri Lalit (91%), and Kufri Lalima (90%).

**Crop duration (90 days):** In northern plains, advanced clone MS/11-664 (42.79 t/ha) produced 5, and 13% higher total tuber yield over Kufri Lalit (40.64 t/ha) and Kufri Lalima (37.93 t/ha) respectively. Performance of this clone (43.64 t/ha) was 44, 12, 21% better than the controls Kufri Manik (30.37 t/ha), Kufri Lalit (39.16 t/ha), and Kufri Lalima (36.11 t/ha) in central plains. In eastern plains, MS/11-664 (30.25 t/ha) yielded better over the controls Kufri Manik (28.11 t/ha), Kufri Lalit (27.25 t/ha), and Kufri Lalima (26.30 t/ha) by 8, 11 and 15% respectively (**Table 4**). Clone MS/11-664 (38.95 t/ha) recorded 16, 9, and 17% higher total tuber yield than controls Kufri Manik (33.44 t/ha), Kufri Lalit (35.59 t/ha) and Kufri Lalima (33.33 t/ha) on an overall basis in whole North-Indian plains. This clone had nearly 91% marketable tuber yield which was comparable with Kufri Manik (91%), Kufri Lalit (91%) and Kufri Lalima (92%).

## Tuber dry matter content

Advanced clone MS/11-664 possessed comparable mean tuber dry matter content (%) of 17 and 19% at 75 and 90 days crop duration, respectively, in comparison to controls Kufri Lalit (18 and 19%) and Kufri Lalima (19 and 20%) in multi-location AICRP on Potato trials during 2018-19 and 2019-20 (**Table 5**). During 2020-21 (**Table 6)**, this clone maintained 17 and 18% tuber dry matter content across the locations at 75 and 90 days as compared to Kufri Manik (17 and 18%), Kufri Lalit (17 and 19%) and Kufri Lalima (18 and 19%).

**Table 4. Mean performance of advanced clone MS/11-664 in AICRP on Potato trials (2018-19, 2019-20 & 2020-21) at 75 and 90 days**

| Regions | Locations | Total tuber yield (t/ha) at 75 days | | | | Total tuber yield (t/ha) at 90 days | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS/11-664 | Kufri Manik | Kufri Lalit | Kufri Lalima | MS/11-664 | Kufri Manik | Kufri Lalit | Kufri Lalima |
| Northern plains | Hisar | 35.35 | 32.99 | 34.68 | 32.65 | 43.64 | 43.64 | 44.25 | 39.24 |
| | Jalandhar | 36.00 | 37.76 | 38.51 | 35.14 | 49.10 | 45.83 | 45.59 | 43.19 |
| | Modipuram | 34.67 | 30.79 | 29.95 | 31.21 | 50.66 | 38.32 | 46.12 | 41.98 |
| | Pantnagar | 23.80 | - | 22.64 | 22.69 | 27.75 | - | 26.60 | 27.34 |
| | Mean | 32.45 | 33.85 | 31.44 | 30.42 | 42.79 | 42.60 | 40.64 | 37.93 |
| | % Yield ± | | -4.12 | 3.22 | 6.68 | - | 0.45 | 5.28 | 12.80 |
| Central plains | Chhindwara | 34.33 | 25.78 | 34.55 | 33.77 | 39.60 | 33.23 | 41.09 | 38.8 |
| | Deesa | 46.19 | - | 42.69 | 42.70 | 54.08 | - | 53.02 | 48.91 |
| | Gwalior | 35.24 | - | 33.41 | 28.91 | 43.43 | - | 39.03 | 33.97 |
| | Kanpur | 37.24 | 28.58 | 28.32 | 26.23 | 45.38 | 27.50 | 31.61 | 32.86 |
| | Kota | 26.16 | - | 21.21 | 23.24 | 44.84 | - | 33.11 | 27.66 |
| | Raipur | 30.27 | - | 30.73 | 29.80 | 34.49 | - | 37.12 | 34.47 |
| | Mean | 34.90 | 27.18 | 31.82 | 30.77 | 43.64 | 30.37 | 39.16 | 36.11 |
| | % Yield ± | | 28.42 | 9.70 | 13.42 | | 43.70 | 11.42 | 20.84 |
| Eastern plains | Bhubaneshwar | 16.94 | 8.45 | 12.78 | 13.12 | 21.50 | 13.72 | 15.59 | 16.81 |
| | Dholi | 26.65 | 29.35 | 25.52 | 27.44 | 29.20 | 33.41 | 27.57 | 27.20 |
| | Faizabad | 30.80 | 33.48 | 30.77 | 24.54 | 35.76 | 37.52 | 35.88 | 33.53 |
| | Kalyani | 26.97 | - | 23.74 | 25.24 | 34.01 | - | 29.98 | 30.63 |
| | Patna | 26.24 | 24.78 | 24.88 | 20.73 | 30.79 | 27.79 | 27.25 | 23.32 |
| | Mean | 25.52 | 24.02 | 23.54 | 22.21 | 30.25 | 28.11 | 27.25 | 26.30 |
| | % Yield ± | | 6.26 | 8.42 | 14.88 | | 7.61 | 10.99 | 15.03 |
| Overall mean | | 31.12 | 28.00 | 28.96 | 27.83 | 38.95 | 33.44 | 35.59 | 33.33 |
| % Yield ± | | | 11.16 | 7.48 | 11.84 | | 16.47 | 9.44 | 16.87 |

## Keeping quality

Advanced clone MS/11-664 was adjudged to be a very good keeper as it exhibited long tuber dormancy (>10 weeks), comparatively less weight loss, rottage, sprout weight, and firm tuber appearance after 75 days of on-farm storage in station trials. Storage study clearly showed that advanced hybrid MS/11-664 has very good keeping quality (**Table 7**) by virtue of having less rottage (0.23%) and total weight loss (7.82%) as compared to new red skin variety Kufri Lalit (2.60 and 9.34%). It had lower rottage and at par total weight loss than the prevalent red skin variety Kufri Lalima (0.99 and 7.64%).

In AICRP on Potato trials (**Table 8**), the clone showed lower total weight loss (12.67%) over the controls Kufri Manik (14.16%) and Kufri Lalit (15.88%). Very good keeping quality of MS/11-664 will benefit small and marginal farmers, those do not store potatoes in cold stores. They store potatoes in heaps under shade or on farm stores for 75 days or till the onset of monsoon which enables them to periodically take out tubers for the local market.

## Usage

Red skin advanced clone MS/11-664 recently released as variety Kufri Lohit is

suitable for table purposes with attractive red coloured ovoid tubers having shallow eyes, which leads to less peeling losses in comparison to Kufri Lalima and Kufri Sindhuri as both have round shaped tubers with deep eyes and their peeling losses

**Table 5. Tuber dry matter content (%) in AICRP on Potato trials (pooled over 2018-19 & 2019-20)**

| Regions | Locations | 75 days | | | 90 days | | |
|---|---|---|---|---|---|---|---|
| | | MS/11-664 | Kufri Lalit | Kufri Lalima | MS/11-664 | Kufri Lalit | Kufri Lalima |
| Northern plains | Hisar | 16.10 | 15.87 | 16.99 | 16.98 | 16.09 | 20.20 |
| | Jalandhar | 13.58 | 15.71 | 18.12 | 14.50 | 16.83 | 18.73 |
| | Modipuram | 13.80 | 15.51 | 18.17 | 14.03 | 15.73 | 19.74 |
| Central plains | Chindwara | 18.26 | 17.28 | 18.15 | 19.28 | 18.29 | 19.24 |
| | Deesa | 15.90 | 17.07 | 18.15 | 19.04 | 19.44 | 21.15 |
| | Gwalior | 15.71 | 16.42 | 19.92 | 18.07 | 18.75 | 21.53 |
| | Kanpur | 21.04 | 21.21 | 21.28 | 23.77 | 24.32 | 24.25 |
| | Kota | 20.37 | - | - | 21.25 | 17.63 | - |
| | Raipur | 19.11 | 19.50 | 19.87 | 20.18 | 20.28 | 20.34 |
| Eastern plains | Bhubaneshwar | 18.08 | 19.36 | 19.24 | 18.46 | 18.72 | 19.10 |
| | Dholi | 16.69 | 17.29 | 17.10 | 19.19 | 20.88 | 19.99 |
| | Faizabad | 17.28 | 17.43 | 17.32 | 18.31 | 18.68 | 18.38 |
| | Kalyani | 18.38 | 18.50 | 21.44 | 23.51 | 21.55 | 22.46 |
| | Patna | 16.23 | 17.05 | 15.47 | 17.25 | 17.65 | 17.88 |
| | Mean | 17.18 | 17.55 | 18.56 | 18.84 | 18.92 | 20.23 |
| | CD (0.05) | Genotypes: 0.16, Genotype × location: 0.52 | | | Genotypes: 0.26, Genotype × location: 0.61 | | |

**Table 6. Tuber dry matter content (%) in AICRP on Potato trials (2020-21)**

| Regions | Locations | 75 days | | | | 90 days | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS/11-664 | Kufri Manik | Kufri Lalit | Kufri Lalima | MS/11-664 | Kufri Manik | Kufri Lalit | Kufri Lalima |
| Northern plains | Hisar | 15.75 | 15.75 | 16.75 | 17.00 | 16.70 | 17.73 | 18.00 | 19.00 |
| | Jalandhar | 13.33 | 14.63 | 15.60 | 16.75 | 15.25 | 15.78 | 16.30 | 17.60 |
| Central plains | Chindwara | 18.40 | 18.20 | 17.85 | 18.13 | 19.00 | 18.53 | 18.55 | 19.00 |
| | Deesa | 14.15 | - | 14.48 | 17.35 | 15.40 | - | 19.23 | 20.33 |
| | Gwalior | 16.47 | - | 17.19 | 18.92 | 16.64 | - | 17.67 | 19.45 |
| | Kanpur | 16.85 | 16.98 | 17.73 | 17.08 | 19.20 | 18.85 | 20.60 | 20.03 |
| | Kota | - | - | - | - | 20.60 | - | 17.83 | 17.08 |
| | Raipur | 18.29 | - | 17.74 | 18.99 | 18.49 | - | 19.07 | 18.99 |
| Eastern plains | Bhubaneshwar | 16.26 | 15.92 | 16.35 | 18.40 | 16.74 | 17.08 | 17.78 | 18.95 |
| | Dholi | 18.18 | 18.48 | 18.21 | 17.55 | 20.14 | 20.16 | 21.24 | 19.13 |
| | Faizabad | 17.40 | 17.71 | 16.30 | 17.50 | 18.48 | 18.89 | 17.09 | 18.40 |
| | Kalyani | 17.72 | - | 18.46 | 18.83 | 21.49 | - | 21.58 | 20.29 |
| | Patna | 14.23 | 14.63 | 15.90 | 16.30 | 16.90 | 16.87 | 16.90 | 16.67 |
| | Mean | 16.42 | 16.54 | 16.88 | 17.73 | 18.08 | 17.99 | 18.60 | 18.84 |
| | CD (0.05) | Genotypes: 0.26, Genotype × location: 0.96 | | | | Genotypes: 0.24, Genotype × location: 0.85 | | | |

**Table 7. Keeping quality (mean of 4 years) in station trials at Modipuram**

| Genotypes | Dormancy | Sprouting (%) | | Loss due to sprouting (%) | Loss due to rottage (weight basis) (%) | Physiological weight loss (%) | Total weight loss (%) | Appearance |
|---|---|---|---|---|---|---|---|---|
| | (<or> than 6 weeks | At 6 weeks | At 75 days | | | | | |
| MS/11-664 | >10 weeks | 0.15 | 29.80 | 0.01 | 0.23 | 7.59 | 7.82 | 4.33 |
| Kufri Lalit | >10 weeks | 33.80 | 60.88 | 0.10 | 2.60 | 6.64 | 9.34 | 4.31 |
| Kufri Lalima | >10 weeks | 2.25 | 30.06 | 0.06 | 0.99 | 6.60 | 7.64 | 4.25 |

**Table 8. Total weight loss (%) under AICRP on Potato trials (mean of 2018-19, 2019-20 and 2020-21)**

| Locations | MS/11-664 | *Kufri Manik | Kufri Lalit | Kufri Lalima |
|---|---|---|---|---|
| Deesa | 17.10 | - | 19.80 | 11.70 |
| *Faizabad | 4.710 | 7.75 | 15.45 | 6.35 |
| Kanpur | 14.70 | 18.00 | 19.00 | 14.00 |
| Modipuram | 11.62 | 15.00 | 9.87 | 7.17 |
| *Patna | 15.20 | 15.90 | 15.30 | 8.20 |
| Overall mean | 12.67 | 14.16 | 15.88 | 9.48 |

*Faizabad (2021-21) and *Patna (2018-19), *Kufri Manik (2020-21)

**Table 9. Late blight reactions of advanced clone MS/11-664 in station trials at Modipuram**

| Genotypes | Field screening | | Detached leaf | |
|---|---|---|---|---|
| | AUDPC | rAUDPC | Lesion area ($cm^2$) | Grading |
| MS/11-664 (4*) | 382.37 | 0.20 | 4.52 | MR |
| Kufri Lalit (3*) | 549.57 | 0.28 | 6.68 | S |
| Kufri Lalima (2*) | 569.69 | 0.29 | 4.70 | MR |

*Number of years screened; Grading: Lesion area ($cm^2$): Up to 1.0- Highly resistant (HR); 1.1 to 2.5- Resistant (R); 2.51-5.0- Moderately resistant (MR), > 5.0 –Susceptible(S)

are high (Luthra *et al.*, 2006 and Kumar *et al.*, 2014). Tubers of this clone seldom exhibit external/internal defects and are not susceptible to skin damage at harvest. The tubers are easy to cook (15-20 minutes) and cooked/boiled tubers are free from any kind of discolouration. Advanced clone MS/11-664 possesses a pleasant flavour, mealy texture, and good organoleptic taste. Thus, the advanced clone's desirable tuber characters, good keeping, and culinary quality will favour its acceptance.

## Disease resistance

Advanced clone MS/11-664 has field resistance to late blight (AUDPC: 382.37; lesion area: 4.52 $cm^2$) as compared to the red-skinned varieties like Kufri Lalit (AUDPC: 549.57; lesion area: 6.68 $cm^2$) and Kufri Lalima (AUDPC: 569.69; lesion area: 4.70 $cm^2$), when investigated under field conditions and through standard detached leaf method (Lal *et al.* 2020), respectively (**Table 9**).

## Production technology

***Crop management:*** Optimum tuber productivity of 36-38 t/ha is achievable with advanced clone MS/11-664 following worked-out nutrition doses and the recommended package of practices. Optimum planting time in north Indian plains remains between the second fortnight of October to the first fortnight of November when the daily maximum day temperature comes down to around 32°C. Potato planting at 20 cm in 60 cm rows for seed size tubers (40-60g) provides optimum tuber yield and seed rate shall be approximately 3.5-4.0 t/ha. Take out seed tubers from the cold store at least 10 days before planting. Do not bring out seed bags in direct sunlight as it may result in rottage due to sudden exposure to high temperatures. Spread the tubers in thin layers under shade in diffused light for sprouting and allow sprouts to become 0.5-1.0 cm long, thick, and green. Carry sprouted tubers to the fields in seed trays or baskets for planting to avoid sprout damage. Fertilizer doses have

been worked out after field experimentation at Modipuram in the west-central plains. This clone responded up to 240 N, 60 $P_2O_5$, and 80 $K_2O$ kg/ha, respectively for 90 days of crop duration of ware potatoes. Hence for seed crops, 150 kg nitrogen (N), 60 kg phosphorous ($P_2O_5$), and 80 kg potassium ($K_2O$) per hectare can be applied. Green manuring before the potato crop is beneficial for crops in several ways including crop nutrition. At planting 10-15 t/ha well rotten FYM may also be applied to provide seed beds with a better tilth and nutrition to the potato crop. These crop management practices shall reduce approximately one-third dose of nitrogen and half doses of phosphorus and potassium. Thus, a half-adjusted dose of nitrogen and full-adjusted doses of $P_2O_5$ and $K_2O$ should be applied at planting. The remaining half-adjusted dose of nitrogen should be applied 20-25 days after planting i.e. at the time of inter-cultivation and earthing. Nutrient management in different agroecologies may differ, so, the regional recommendation may be fine-tuned and adopted for obtaining optimum productivity of this clone. Pre-sowing irrigation is done to ensure uniform emergence. If this is not given then the first irrigation should be done 4-6 days after planting. Post planting irrigations are kept light and applied subsequently at 7-10 days intervals in sandy loam soil and 10-12 days in heavy soil. Potato ridges must not be submerged under water in any case and arrangements for drainage should also be developed keeping in view unseasonal rains during crop season (Rawal *et al*., 2021).

***Plant Protection Measures:*** To manage cutworms, white grubs, beetles, and *leaf-eating* caterpillars, apply cartap hydrochloride 4G @20 kg/ha during earthing-up. It will also take care of sucking *pests* like leaf *hoppers* and aphids. For seed *crops*, place yellow sticky traps (15x30 $cm^2$ size) just above the canopy height @ 60 traps/ha at equidistance from each other for mass trapping of white flies/aphids. Seed treatment is done with imidacloprid (200SL) @ 0.04% (4 ml/10 l water) for 10 minutes before planting. The first spray of imidacloprid (200SL) @ 0.03% (3 ml/10 l water) is completed at 85% crop emergence followed by a second spray with thiamethoxam (25 WG) @ 0.05% (5 gm/10 l water) 10-15 days after the first spray. Although the variety is moderately resistant to late blight, however, prophylactic spray just at the time of canopy closure with mancozeb or propineb or chlorothalonil @ 0.2% (2 gm/l water) followed by *need-based* application of cymoxanil + mancozeb or dimethomorph + mancozeb or fenamidone + mancozeb @ 0.3% (3 gm/l water) is required for effective management of late blight. Insecticide sprays are not required in the case of table potato crops and integrated pest and disease management recommended by the institute should be followed (Rawal *et al*., 2021).

***Harvesting:*** Irrigation should be stopped 10-12 days before haulm killing and harvesting may be done 10-15 days after haulm cutting at proper soil moisture. After harvest, produce should be kept under shade in heaps covered with 30 cm thick available straw or crop residue for 10-15 days. Both of these measures shall help in curing the tuber skin. All damaged and rotten tubers should be removed and graded to fetch a better price in the market. Potatoes are packed in 45-50 kg gunny or leno bags and labeled either for selling in the market or storing in cold storage (Rawal *et al*., 2021).

## ADAPTABILITY

Advanced clone MS/11-664 named and released as variety Kufri Lohit has performed well in multi-location trials conducted under AICRP on Potato and has been recommended

for cultivation in North-Indian plains (Eastern and Central plains). This variety can also successfully be grown in northern plains due to its yield advantage, particularly to meet the seed requirement of regions having a preference for red-skin tubers. Thus variety Kufri Lohit can easily be adopted in Orissa, Bihar, West Bengal (Eastern plains); Madhya Pradesh, Gujarat, Rajasthan, Chhattisgarh (Central plains), and Haryana, Punjab, Uttar Pradesh (Northern plains).

## CONCLUSION

Kufri Lohit is a medium maturing red skin variety and can be a better choice for farmers and consumers where red-skinned potatoes are preferred. The variety produces attractive red coloured, ovoid tubers with shallow eyes, cream flesh, and mealy texture. This variety possesses approximately 18% tuber dry matter content and has very good keeping quality. It is responsive to crop nutrition and yields 36–38 t/ha total tuber yield under optimum crop management. Its export potential can also be harnessed in the coming time for destinations like Bangladesh, Bhutan, Nepal, Pakistan, and Philippines, where red-skinned tubers are traditionally preferred (Pandey *et al.*, 2000 and Luthra *et al.*, 2004).

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors.

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# IRRADIATED POTATOES IDENTIFICATION BY THERMOLUMINESCENCE AND SEED TUBERS GROWTH ANALYSIS IN CASE OF LOW GAMMA DOSE AND LATE IRRADIATION

**Asma Benaidja[1,2], Rabah Yefsah[3], Belkacem Mansouri[3] and Faycal Kharfi[2,4*]**

**ABSTRACT: In this work, irradiated *DESIREE* potato was successfully identified by thermoluminescence technique for gamma dose up-to 1500 Gy. Selected SPUNTA and DESIREE potato seed tubers were also cultivated after being irradiated with different gamma low doses, varying from 10 to 150 Gy. Effects of gamma irradiation on plant growth, sugar content, and yield were studied. The potato seed tubers were late irradiated three weeks before planting. The analysis of tuber's progenies shows non-mutation in terms of eye colour, skin colour and texture for low doses below 25 Gy. The emergence percentage of the plants were optimal for the dose interval of 10-25 Gy. No emergence ability has occurred at 55 Gy and 75 Gy and higher dose for *SPUNTA* and *DESIREE*, respectively. Irradiation with 10-25 Gy promoted tubers formation. There was no morphological growth enhancement at 25 Gy and higher dose, and no survival of the plants at 65 Gy and 85 Gy and higher doses for *SPUNTA* and *DESIREE*, respectively. The effects of gamma radiation on irradiated but not planted tubers show that total sugars content increases from ~1.5% to ~3.5% for low doses and keeps constant for higher doses. The harvested tubers produced from irradiated planted seeds show a constant sugar content even dose changes and non-influence of the irradiation on total sugar consumption and production. This study indicates too that late irradiation with low dose below 25 Gy (10Gy) significantly increases leaves number (+~75%) and growth capability in terms of tuber's weight (15-30%).**

**KEYWORDS:** Potato; Gamma irradiation; Plant Growth; Irradiation identification; Total sugar metabolism.

## INTRODUCTION

During the last four decades, irradiation has been established as a robust technique that can be used to induce mutations in plants allowing the production of better quality varieties with higher yields and greater resilience to water stresses. In the field of crops and diseases of plants irradiation has been extremely useful. Indeed, irradiation can help to upgrade cultivars of vegetatively propagated plants. The International Atomic Energy Agency (IAEA) report also describes terminology used for each propagation following irradiation treatment (FAO/IAEA, 2003; IAEA, 2018). Potato is a vegetative propagated crop. Potato cultivars are conventionally maintained as true clones through successive planting of tubers. Irradiation is able to play a major role in the enhancement of shelf life and quality characteristics of potato tubers by its effects on their physico-mechanical, chemical, and physiological properties (Al-Safadi *et al.*, 2000; Baskaran, 2007; Afrasiab and Iqbal, 2010; Ghosh and Das, 2014; Mahto and Das, 2015; Muley *et al.*, 2019). The G0 and class A studied tubers are prepared by in-vitro cultivation in laboratory (G0) and taken from those selected and stored in order to be used for further multiplication by planting them in soil in the conventional manner for

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the production of seed potato crop (Class A). Irradiation of potato cultures and their subsequent multiplication through macro-tubers production by both methods would thus permit a method for producing variants of the enhanced cultivars.

This work aims to study the effect of low dose irradiation on lethal and growth of potato tubers and on some others physiological properties. The main objective is demonstrate how irradiation can helps in the selection of healthy varieties of *SPUNTA* and *DESIREE* potato tubers that give optimal production yields. In this paper, the results of a study on irradiated potato seed tubers and produced tubers and cultivars are reported.

## MATERIALS AND METHODS

### Potato tubers selection and sampling

In this study, selected tubers are subdivided into 11 sub-groups to be irradiated with different doses except the first one which was not irradiated (reference). The first selection of tubers was performed to get a uniform tubers sample with approximately similar morphological characteristics in terms of average tuber weight, average tuber size, average number of tubers per plant, sprout size, average and number of eyes. Selecting plants for seed is the key to getting healthy seed. A positive selection was followed in our study.by choosing plants that display good growth and show no signs of bacterial wilt and/or viruses. Two varieties of potato seed tubers were studied *DESIREE* and *SPUNTA* of G0 generation and class A. The *DESIREE* potato is a medium to mid-late, productive variety. Rustic, giving large tubers with red skin and yellow flesh, of good preservation. Good resistance to cooking and does not blacken (http://plantdepommedeterre.org/index/fiches-descriptives-des-varietes-de-pomme-de-terre/desiree). The *SPUNTA* potato is of Dutch origin and one of the most cultivated varieties thanks to its excellent yield. It is a variety with large, elongated, and yellow-skinned tubers (http://plantdepommedeterre.org/index/fiches-descriptives-des-varietes-de-pomme-de-terre/spunta). The class A seed-tubers were rigorously selected from harvested tubers by conventional cultivation that were kept dormant for four months and irradiated three weeks before planting. The G0 seed tubers were produced in laboratory by in-vitro cultivation, and irradiated one month after reaching the final requested morphological and physiological growth and three weeks before planting. To obtain results statically acceptable a sufficient number of tubers was considered in this study for each irradiated sub-group of tubers. Analysis of standard deviation, variance and least significant differences of means ($P<0.05$) were performed.

### Gamma irradiation protocol

The Gamma irradiator used is made up of three cylindrical sources of $^{60}Co$ ORIS-COP4 (Fig.1). The sources are arranged vertically in a stainless steel source holder. The sources are 384 mm in length and high 26.6 mm in diameter. The initial activity of the source is 3.56 kCi on October 8$^{th}$, 2002.

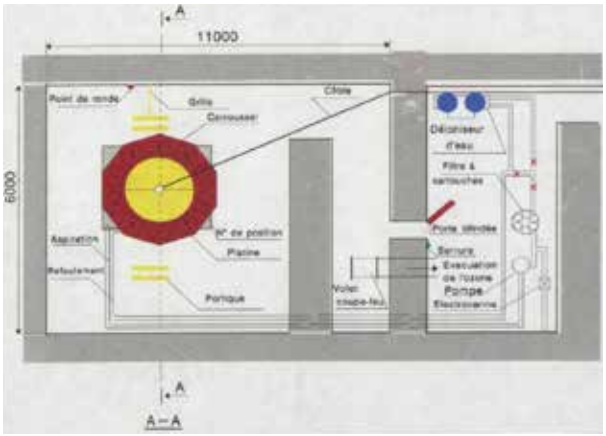



*Fig.1 The Gamma irradiator*

The actual activity when irradiating potato tubers (October 15th, 2019) is about 381 Ci. The actual measured dose rate is 3.22 Gy/mn. The Fricke dosimetry was used for the calibration and the dose rate measurement. *DESIREE* and *SPUNTA* tubers sub-groups were irradiated for different doses of 10, 25, 35, 45, 65, 75, 85, 100 and 150 Gy.

## Irradiation identification

Thermoluminescence (TL) of the silicate minerals included in foods is a powerful method for the identification of irradiated products. By virtue of its advantages in the prolonged preservation of foods and seeds, irradiation has been practiced on many agricultural products for various purposes, such as potatoes, spices, fruits, and seafood (Khan and Delincée, 1995; Raffi *et al*., 2000; Kwon *et al*., 2002; Bayram, and Delincée, 2004; D'Oca *et al*., 2009; Chen *et al*., 2014; Todoriki *et al*., 2014). The irradiation identification process is based on mineral extraction from irradiated food being irradiated. The standard extraction procedure of silicate minerals from potato is described by the European Standard, EN 1788 (2001). In this work, similar adapted procedure was used for the mineral extraction from studied potatoes (DESIREE) that was already used in our laboratory on black pepper (Kharfi and Ketfi, 2018).

TL signals were read with the Risø National Laboratory TL/OSL-DA-20 luminescence reader (Risø, 2015). The thermoluminescence signals were all collected under the same conditions presented in Table 1.

**Table 1 Conditions for the thermoluminescence signal reading**

| | |
|---|---|
| Luminescence reading mode | Thermoluminescence |
| Maximum reading temperature | 252 °C |
| Heating rate | 5 ° C/s |
| TL signal sampling | 140 points over the range 0 °C to 252 °C |
| Analyzed sample weight | 2 mg |

## Cultivation and soil quality

In this study, a loamy experimental soil is used. The most prevalent component is sand with clay and silt. This soil is suited to potatoes (Tantowijoyo and De Fliert, 2006). A controlled cultivation under plastic and greenhouse conditions is considered. The soil was first prepared by screening and addition of fertile and breeding grounds. Pre-irrigation with the application of a basic NPK fertilizer (15.15.15) is practiced over the whole cultivation period. The irrigation was with plain water twice a week. During cultivation, the soil and the plant care has been assured by the weeding the soil, the spreading of fertilizers mixed with urea, the treatment of plants with fungicide and insecticide, as well as the treatment against mildew.

## Physiological analysis of seed tubers

The potato plant consists of the following parts: leaves, stems, roots and tubers. The potato growth can subdivided into the following main stages: sprout development stage, vegetative growth stage, tuber initiation stage, tuber-bulking stage, and tuber maturation stage. In our study, after planting, the effect of low dose irradiation on selected seed tubers was analysed in terms of some physiological characteristics of the plant during its growth. The considered criteria are the stem height, the root length, the duration until plant emergence from the soil, and growth speed.

## Sugar content analysis

It is known that the sugar content in the potato tuber determines the optimum harvest time, the type of processing and its handling during storage. The potato is made up of 10-18% of starch and 1-7% of total sugars (Saar-Reismaa *et al*., 2020). The estimation of these sugars in the tubers of the potato allow the assessment of the

food quality as well as growth capability (Rady and Guyer, 2015; Duarte-Delgado *et al*., 2016). In this work, total soluble sugar amounts (sucrose, glucose, fructose, their methyl derivatives and polysaccharides) were determined before irradiation and after irradiation for the planted and not-planted seed tubers in their fresh matter (after harvest). The experimental procedure based on Phenol method described by Dubois *et al*. is used ([Dubois *et al*., 1956; Krishnaveni *et al*., 1984; Mecozzi, 2005). The sugar amounts were measured using a JENWAY 6405UV/VIS spectrophotometer with wavelength of 485 nm after accurate calibration. This spectrophotometry analysis method measures total amount of a chemical substance through the determination of its absorbance in a suitable solution by measuring the absorbed light passing through it.

## RESULTS AND DISCUSSION

Fig. 1 depicts typical glow curves (TL signals) of the silicate minerals extracted from studied potatoes after irradiation a dose of 10 Gy, 20 Gy, 30 Gy, 50 Gy, 150 Gy, 1000 Gy and 1500 Gy. The curves consist of a very sharp peaks centered at ~97°C. The obtained stable thermolumeiscnence peaks allow the identification of the irradiated potatoes. Fig. 2 illustrates the dependence between the irradiation dose and the TL intensity as obtained with just one test. Our objective of irradiated potatoes identification is achieved. Moreover, such TL-Dose dependence curve (Fig. 2) may be used for the irradiation dose determination but further investigation are necessary to reach suitable accuracy on dose level. Indeed, in case of dose deviation, the TL dose response of the separated silicate minerals from potatoes can be corrected by considering a protocol based on dose recovery tests and dose measurement repetition and then a calibration curve can be constructed.

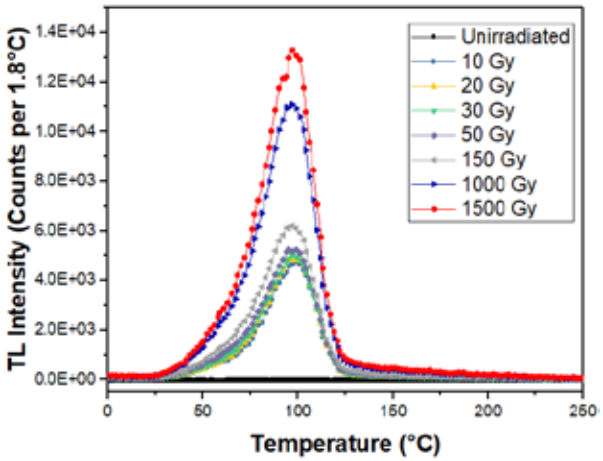



*Fig. 1. TL curve of minerals separated from unirradiated potato showing background and TL curves irradiated potatoes after exposure to 10, 20, 30, 50, 150, 1000 and 1500 Gy around Gamma irradiator.*

Fig. 3 illustrates the tuber and the plant physical aspect of the studied *DESIREE* and *SPUNAT* potato varieties irradiated with different low doses, after 80 days from planting. It is clear that *DESIREE* tubers have a difficulty to grow when irradiated with a dose of 75 Gy or higher. The same thing is noted for *SPUNTA* but for a dose of 55 Gy or higher. The planted tubers that produced plants, and gave new tubers were analysed in terms of variation in tuber skin, eye colour,

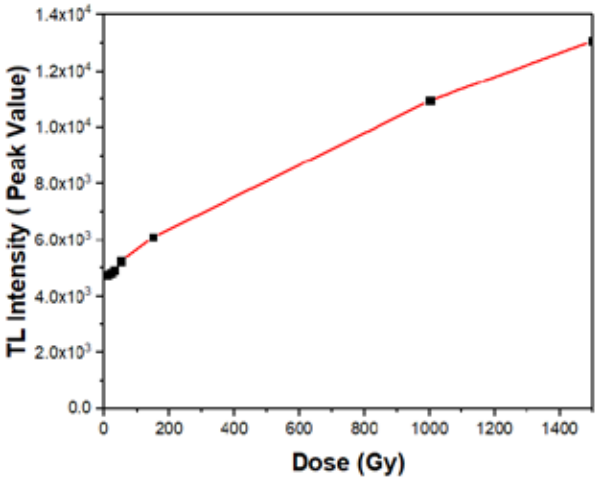



*Fig. 2. The potato minerals response to gamma doses*




*Fig. 3. SPUNTA (top) and DESIREE (bottom) (G0) potato tubers and plants growth irradiated with different doses (0-150 Gy), after 80 days from planting.*

skin texture, tuber shape and eye-depth. Data indicated no significant differences between tubers for all studied traits and for all related doses.

The obtained results show that the plant emergence is delated due to the irradiation. Fig. 4 shows that emergence delay starts to be significate from a dose of about 45 Gy for both potato varieties. Doses of 65 and 85 Gy are lethal for *SPUNTA* and *DESIREE* seed tubers, respectively.

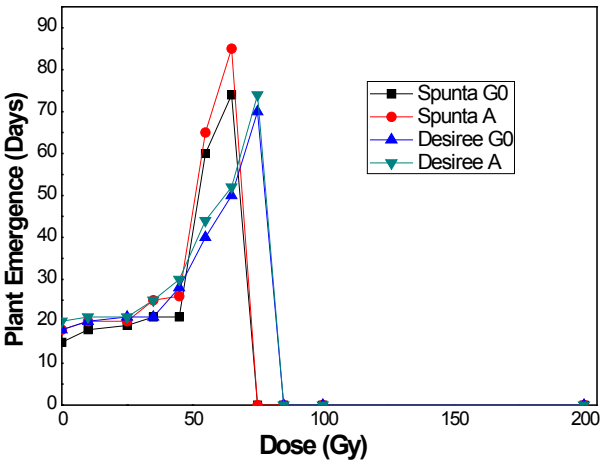



*Fig. 4. Emergence time from soil after planting of irradiated SPUNTA and DESIREE*

Figs. 5 and 6 show the stem height and the root length of *SPUNTA* and *DESIREE* after 60 and 80 days from planting. The results obtained show clearly and at first sight that the growth of the stems of the plants is correlated with that of the roots. The growth of irradiated tubers is similar to that of the not-irradiated reference tuber up to a dose of 25 Gy for *SPUNTA* and 45 Gy for *DESIREE*. From these last doses, growth is delayed until is completely stopped at the lethal doses already determined for both variants and generations of studied potatoes. It is very important to mention here that tubers weight analysis at the above mentioned planning duration (60 and 80 days) show that the tubers of 10 Gy are heavier by an amount of 15-30% than the non-irradiated tubers indicating better yield.

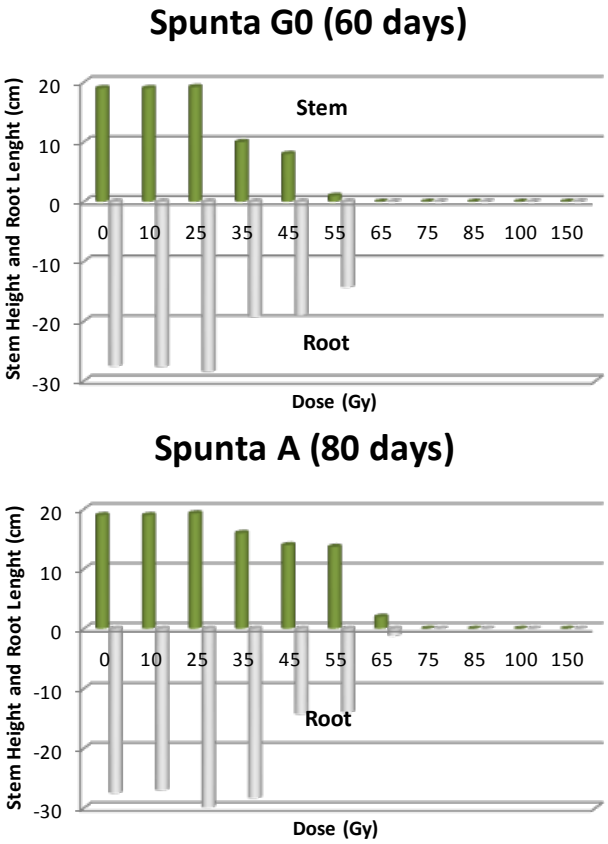



*Fig. 5. Irradiated SPUNTA stem and root growth after 60 and 80 days from planting*

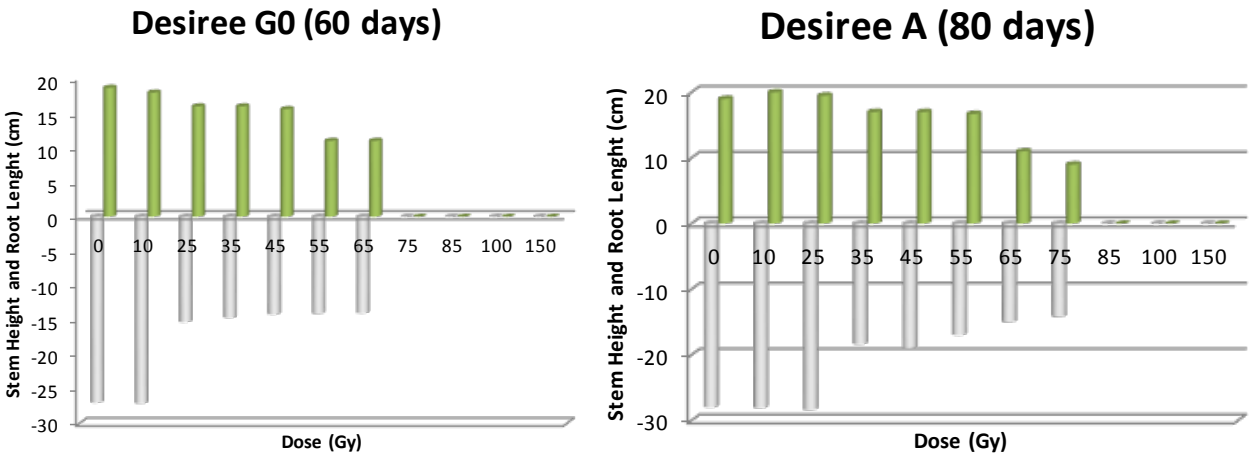



*Fig. 6. Irradiated DESIREE stem and root growth after 60 and 80 days planting*

Fig. 7 shows an analysis of the plants growth. The most important feature that can noted from this figure is the fact that the irradiated tubers with maximum doses of 25 Gy for *SPUNTA* and 45 Gy for *DESIREE* present relatively the same growth status and reach the same maturation level in terms of stem height at the last stage of growth.

The total sugars concentration (percentage in weight)) was also studied for the cases of irradiated and not-planted tubers, and harvested ones. The results show that the sugar

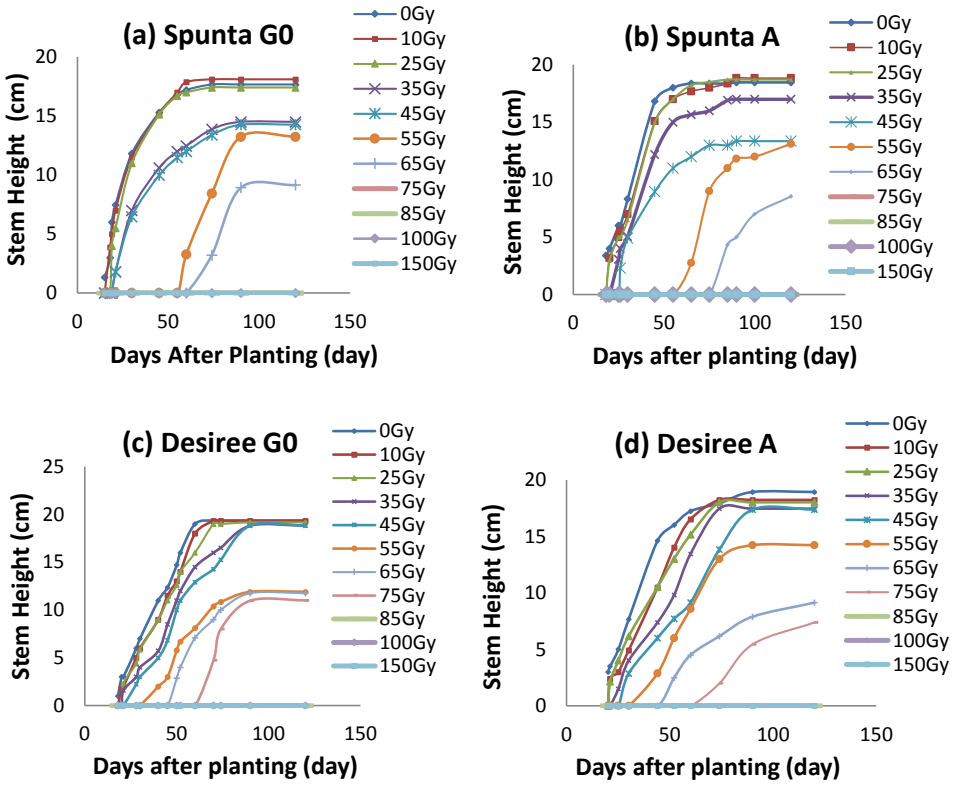



*Fig. 7. Growth speed and behaviour of irradiated SPUNTA (a, b) and DESIREE (c, d)*

concentration of the not-planted tubers was increased proportionally with the irradiation dose for both varieties of potato with their generations (Fig. 8 and Fig. 9). At the opposite, the sugar concentration of the harvest tubers was found to be constant whatever the dose of the original planted seed tubers (parents) (Fig. 10).

From the above describer results, the main findings can be discussed as follows.

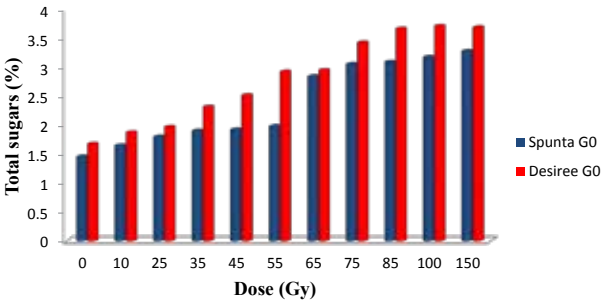



*Fig. 8. Sugar concentration in irradiated and not-planted SPUNTA and DESIREE (G0) measured just after the harvest of the planted ones*

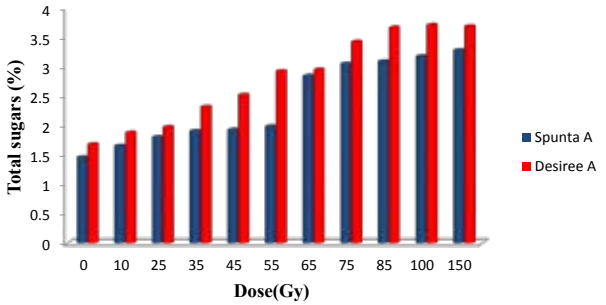



*Fig. 9. Sugar concentration in irradiated not-planted SPUNTA and DESIREE (A) measured just after the harvest of the planted ones*

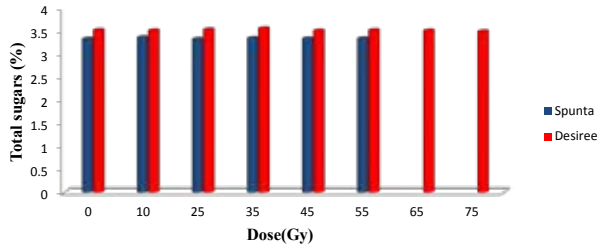



*Fig. 10. Sugar concentration in irradiated and planted SPUNTA and DESIREE after harvest*

The irradiation prolonged the time between planting and emergence and reduced the height of the stem and length of root from threshold doses of 25 Gy for *SPUNTA* and 45 Gy for *DESIREE*. Under the normal culture conditions considered, the number of leaves and branches was significantly increased for a dose of 10 Gy. No emergence ability occurred at 65 Gy and 85 Gy and higher doses for *SPUNTA* and *DESIREE* seed tubers, respectively. Radiation with 10-25 Gy promoted tuber formation, and increased the average number and diameter of tubers per plant. Our results are globally in good agreement with those presented in the study of Cheng *et al*. (Cheng *et al*., 2010). This study indicated that relatively late irradiation just three weeks before planting with low dose of 10 Gy significantly enhance to seed-tubers yield by enhancing the tubers weight with 15-30% amount without any abnormal impact on the morphological growth of the plants. Total sugars content (total carbohydrates) significantly increased a function of dose (0-150 Gy) from ~1.5% to ~3.5 % for irradiated but not planted seed-tubers stored under normal conditions during the whole cultivation period while it was found constant (~3.5%) for the harvested tubers produced by the irradiated seed-tubers. Total carbohydrates concentration was measured in all cases at the same time just after harvest even for the not-irradiated stored tubers. This findings means that irradiation with low doses (below lethal doses of 65 and 85 Gy) has no-effect on the sugar production and transformation metabolism in the plant when compared to the plant of the not-irradiated and planted seed-tuber. For the not-planted seed tubers, the concentration in sugars increased for higher dose and this may be due to utilization of sugars as substrate for respiration and to fight against the effects of irradiation because these tubers sprouted and hence may have utilized the excess sugars

for energy production during sprouting with higher respiration rate. Rezaee *et al*. demonstrate in their study that earlier and late irradiation of potato tubers after harvest has not the same effect on sugar accumulation in the tubers. This study indicates too that the total sugar accumulation is influenced by the dose as we demonstrate in our study. Inverse effect was observed on the non-reducing sugar because of very late irradiation. Our findings agree to those reported in this study (Rezaee *et al*., 2013). This study indicates too that late irradiation with low doses below 25 Gy significantly increases leaves number (+~75%) and growth capability in terms of tubers number and weight (10Gy).

## CONCLUSION

In this work, irradiated potatoes were efficiently identified by thermoluminescence technique. Effects of gamma irradiation on plant growth, sugar content, and yield were studied for two varieties of potato seed tubers, *DESIREE* and *SPUNTA*, produced by conventional and in-vitro cultivation. Non-mutation in terms of eye colour, skin colour and texture for the low dose below 25 Gy. Our study show that relatively late irradiation, three weeks before planting, with 10-25 Gy low dose is beneficial for tubers formation and growth and has a direct impact on yield. The emergence percentage, in terms of plant height and root length of the plants were optimal for the dose interval of 10-25 Gy with no emergence ability at 55 Gy and 75 Gy and higher dose for *SPUNTA* and *DESIREE*, respectively. Total sugar content was accurately measured by spectrophotometry. Low doses has no-effect on the total sugar production and transformation metabolism in the plant. For the not-planted seed tubers, the concentration in total sugars increased for higher dose and this may be due to the utilization of sugars as substrate for respiration and to the irradiation effects too.

## ACKNOWLEDGEMENT

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## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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# KUFRI MANIK: A RED- SKINNED BIOFORTIFIED POTATO VARIETY

**Shambhu Kumar[1], Dalamu[2]*, Jagdev Sharma[3], SK Luthra[4], Vinay Bhardwaj[5] and SK Chakrabarti[6]**

**ABSTRACT: Kufri Manik is a medium maturing, main season, nutrient-rich table potato variety suitable for cultivation in Eastern plains. It is a clonal selection from the cross between Kufri Arun × CP3192. Its plants are tall with field resistance to late blight. The variety produces attractive, deep red, round shaped tubers with medium eyes and yellow flesh. Kufri Manik is nutrient-dense variety by virtue of high anthocyanin (68 mg/100g FW), phenols (71 mg/100g FW), Zinc (33 ppm), Iron (30 ppm) as compared to red skin control varieties like Kufri Lalima and Kufri Lalit. It is fertilizer responsive and can yield 23-25 t/ha under optimum agronomical practices. Kufri Manik has performed well in multi-location trials conducted under AICRP on Potato and has been recommended for cultivation in eastern plains (Bihar, Orissa, West Bengal, Assam and Eastern Uttar Pradesh).**

**KEYWORDS:** Potato, biofortification, yield, late blight, Kufri Manik, Eastern plains

## INTRODUCTION

Potato is the third most consumed food crop globally after wheat and rice. Potato yields more dry matter, well-balanced protein and more calories per unit area of land and time than other major food crops. Potatoes have the highest overall nutrient-to-price ratio than other vegetables and are a major staple food worldwide (Drewnowski, 2013). But being the staple food, still, there is a need to improve the nutritional quality of the most consumed non-grain food crop i.e. 'Potato'. According to the nutritional profile, potatoes are a good source of carbohydrates, protein, minerals, dietary fibres, as well as vitamin C, B6, K, Fe and folate (Robertson *et al*., 2018). Potatoes can deliver additional nutrients and dietary fibres if cooked without peeling. To boost the nutritional value, biofortification has emerged as an upcoming approach with enormous potential. Anthocyanin and carotenoid pigments impart colour to the crop. The accumulation of carotenoids renders white, cream, and yellow whereas anthocyanin pigments produce red, purple, and blue potatoes. Potatoes also constitute significant levels of micro-nutrients *viz*., iron and zinc content (Burgos *et al.,* 2007) in the broad genetic resources that can be introgressed through selection and varietal development.

The cultivation of potatoes is stretched to different agroclimatic zones of India. Mostly white/yellow fleshed potatoes were preferred by the people but coloured potatoes nowadays have a rising demand by consumers due to its enhanced nutrient characteristics and this choice also varies from region to region. In Eastern plains, some stretches of North Eastern states and Jammu and Kashmir, red-skinned potatoes are preferred; purple-black or purple skinned varieties are popular in some pockets of

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Himachal Pradesh and North Eastern regions. Some coloured genotypes, especially red and purple skinned and fleshed (Luthra *et al*., 2020; Dalamu *et al*., 2023) advanced clones have been developed by CPRI Shimla. Considering consumer orientation to nutrient-dense potatoes in addition to other major objectives for developing a variety the present investigation reports development of nutrient-rich biofortified variety Kufri Manik for Eastern plains.

## BACKGROUND

Kufri Manik (PS/06-88) was developed at ICAR-Central Potato Research Institute, Regional Station, Patna from the cross Kufri Arun × CP3192 in 2005. The female parent Kufri Arun is a medium maturing table potato variety suitable for cultivation in north Indian plains (Luthra *et al*., 2006). Its plants are tall (80-85 cm) and bear red, ovoid tubers, shallow to medium eyes and creamy-light yellow flesh with good keeping quality. The male parent CP3192 (var. 27/40) is an exotic genotype from Peru. The plants are erect and produce medium to large-sized, light red round compressed tubers with medium-deep eyes and yellow cream flesh. The hybridisation was carried out in the year 2005 at ICAR-CPRS, Kufri, Himachal Pradesh. Pedigree details of Kufri Manik are detailed in Fig 1.

The clone PS/06-88 successfully passed through seedling and initial clonal generations and it was evaluated in a preliminary yield trial (PYT), two confirmatory yield trials during 2009-2010, 2010-2011, and 2011-2012 at ICAR-CPRS, Patna, Bihar. Based on superior performance advanced clone PS/06-88 was introduced in AICRP (Potato) for mult-location testing. In AICRP (Potato), advanced clone PS/06-88 was evaluated in multi-locations replicated trials (2013-2014 & 2014-2015) at four locations, i.e. Bhubneshwar, Faizabad, Jorhat and Patna and on-farm trials (2015-16) at five locations namely Dholi, Faizabad, Jorhat, Kalyani and Patna; and (2017-18) at six locations *viz*., Bhubneshwar, Dholi, Faizabad, Jorhat, Kalyani and Patna in Eastern plains. The advanced clone PS/06-88 was recommended for release in the 36th AICRP (Potato) group meeting held during September 08-11, 2018 at SDAU, Sardarkrushinagar, Gujarat. Subsequently, advanced clone PS/06-88 has been notified as variety Kufri Manik by Central Sub-Committee on Crop Standards Notification and Release of Varieties for Horticultural Crops, Ministry of Agriculture, Department of Agriculture and Co-operation, Government of India, New Delhi vide gazette notification S.O. No. 4272 (E) dated 1st April 2021.

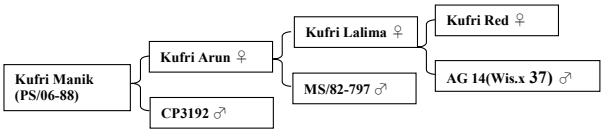



*Fig. 1. Pedigree of Kufri Manik*

## VARIETAL DESCRIPTION

**Plants:** Tall, canopy semi-compact, stem medium thick, predominantly green, wings highly developed and straight.

**Foliage:** Grey-green, leaves close, leaflet width narrow, leaflets ovate, leaflet coalescence absent, rachis green, midrib green.

**Flower:** Flowering medium, inflorescence medium-sized, floral stalk green, floral stalk-pedicle articulation clearly visible and located above the middle, calyx green, corolla red-violet, corolla shape semi-stellate, anther orange, anther cone normally developed, styler length longer than stamen column and stigma bi-lobed.

**Tubers:** Tubers (8-10), deep red, round tuber, medium eyes, eyebrows normal, flesh yellow (Fig. 2), texture waxy.

## Sprout

Red-purple, spherical, pubescence at the sprout base is weak



DNA Fingerprint of advanced potato hybrid, PS/06-88 with STU and STIIKA markers (ABI 3500 Genetic analyzer)

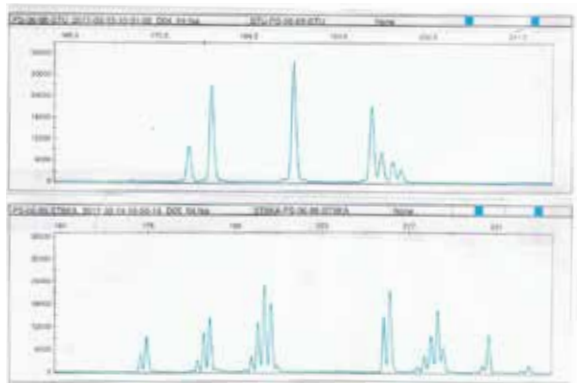


*Fig. 2. Kufri Manik: Leaf, Inflorescence, tubers, sprout and DNA fingerprint profile*

## YIELD PERFORMANCE

***Station trials:*** In station trials at Patna during three consecutive years, i.e. 2009-10, 2010-11 and 2011-12, advanced clone PS/06-88 consistently out-yielded the controls Kufri Arun and Kufri Lalima at 75 days (**Table 1**). On an average, PS/06-88 (27.50 t/ha) yielded 20 and 24% higher total tuber yield as compared to controls Kufri Arun (22.92 t/ha) and Kufri Lalima (22.12 t/ha).

***Multi-location testing in AICRP (Potato):*** In AICRP (Potato) advanced clone PS/06-88 was evaluated in multi-locations replicated trials (2013-2014 to 2014-2015) and two on-farm trials (2015-16 and 2017-18) in Eastern plains.

The results of the replicated trials in Eastern plains Bhubneshwar (BHN), Faizabad (FZB), Jorhat (JRH) and Patna (PAT) during 2013-14 & 2014-15 at 75 days showed superiority of PS/06-88 (20.01 t/ha) for total tuber yield over Kufri Lalima (19.17 t/ha) and Kufri Arun (18.42 t/ha) by a margin of 4

**Table 1. Performance of PS/06-88 at Patna in station trials during 2009-2012**

| Genotype | Total tuber yield (t/ha) at 75 days | | | | % yield increase over control varieties |
|---|---|---|---|---|---|
| | 2009-10 | 2010-11 | 2011-12 | Average | |
| PS/06-88 | 25.09 | 27.94 | 29.46 | 27.50 | |
| Kufri Arun | 19.25 | 26.36 | 23.15 | 22.92 | 19.98 |
| Kufri Lalima | - | - | 22.12 | 22.12 | 24.32 |
| CD (0.05) | 1.38 | 1.89 | 1.48 | | |

**Table 2. Total tuber yield (t/ha) of PS/06-88 in replicated trials at 75 days**

| Genotype | 2013-14 | | | | | 2014-15 | | | | | Overall Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BHN | FZB | JRH | PAT | Mean | BHN | FZB | JRH | PAT | Mean | |
| PS/06-88 | 13.89 | 15.47 | 21.30 | 29.94 | 20.15 | 17.05 | 27.67 | 13.07 | 21.71 | 19.87 | 20.01 |
| Kufri Lalima | 15.33 | 14.47 | 19.91 | 24.43 | 18.54 | 23.29 | 25.50 | 15.48 | 14.97 | 19.81 | 19.17 |
| Kufri Arun | 8.93 | 15.00 | 17.69 | 25.3 | 16.73 | 21.85 | 27.00 | 14.72 | 16.88 | 20.11 | 18.42 |
| CD (0.05) | Y = 0.68, L= 0.96, Y × L =1.36, G = 0.83, Y × G =1.17, L × G =1.67, Y × L × G =2.35 | | | | | | | | | | |

and 9% respectively at 75 days (**Table 2**). At 90 days, PS/06-88 yielded equal total tuber yield (23 t/ha) with control Kufri Lalima (23 t/ha), however it has an advantage of 3% over Kufri Arun (22 t/ha) (**Table 3**). Marketable tuber yield (t/ha) of PS/06-88 was observed 17.08 t/ha while controls Kufri Lalima and Kufri Arun yielded at par (16.94 t/ha and 16.79 t/ha, respectively) at 75 days maturity. At 90 days, PS/06-88 yielded at par marketable yield (19.34 t/ha) than the controls Kufri Lalima (19.75 t/ha) and Kufri Arun (19.28 t/ha). PS/06-88 produced nearly 86% marketable yield at both 75 and 90 days crop durations.

During third year, in on-farm replicated trials, pooled analysis of five locations (Dholi, Faizabad, Jorhat, Kalyani and Patna), PS/06-88 (18.22 t/ha) out yielded Kufri Lalit (16.89 t/ha) by a margin of 9% at 75 days, while at 90 days, PS/06-88 (23.72 t/ha) out yielded Kufri Lalit (22.93 t/ha) by a margin of 3% (**Table 4**). PS/06-88 produced nearly 80 and 83% marketable tuber yield at 75 and 90 days, respectively. PS/06-88 also possessed high tuber dry matter of 20% as compared to 19% in Kufri Lalit at 90 days.

The on-farm trials during 2017-18 were conducted at **s**ix centres in Eastern plains i.e Bhubneshwar, Dholi, Faizabad, Jorhat, Kalyani and Patna, where PS/06-88 out yielded the controls Kufri Lalit and Kufri Lalima, at all centres, except Kalyani at both 75 and 90 days harvesting (**Table 5** and **Table 6**). On an average, PS/06-88 (20.50 t/ha), out yielded the control Kufri Lalima (19.19 t/

**Table 3. Total tuber yield (t/ha) of PS/06-88 in replicated trials at 90 days**

| Genotype | 2013-14 | | | | | 2014-15 | | | | | Overall mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BHN | FZB | JRH | PAT | Mean | BHN | FZB | JRH | PAT | Mean | |
| PS/06-88 | 13.19 | 19.83 | 22.78 | 32.99 | 22.20 | 17.04 | 32.67 | 17.50 | 24.73 | 22.98 | 22.59 |
| Kufri Lalima | 14.19 | 17.81 | 20.97 | 31.29 | 21.06 | 23.43 | 30.57 | 20.83 | 21.58 | 24.10 | 22.59 |
| Kufri Arun | 9.48 | 19.86 | 18.98 | 30.28 | 19.65 | 21.99 | 32.50 | 18.23 | 23.53 | 24.06 | 21.86 |
| CD (0.05) | Y =0.57, L= 0.80, Y × L =1.13, G = NS, Y × G =0.98, L × G =1.39, Y × L × G =1.97 | | | | | | | | | | |

**Table 4. Total and marketable tuber yield (t/ha) of PS/06-88 in on-farm trials (2015-16) at 75 and 90 days (Dholi, Faizabad, Jorhat, Kalyani and Patna)**

| Genotype | 75 Days | | | 90 days | | |
|---|---|---|---|---|---|---|
| | Total yield (t/ha) | Marketable yield (t/ha) | Tuber dry matter % | Total yield (t/ha) | Marketable yield (t/ha) | Tuber dry matter % |
| PS/06-88 | 18.22 | 14.52 | 18.03 | 23.72 | 19.64 | 19.90 |
| Kufri Lalit | 16.89 | 13.60 | 18.62 | 22.93 | 19.52 | 18.99 |
| CD (0.05) | N/A | N/A | N/A | N/A | N/A | N/A |

**Table 5. Total tuber yield (t/ha) of PS/06-88 (2017-18) in Eastern plains at 75 days in on-farm trials**

| Genotypes | 75 days | | | | | | |
|---|---|---|---|---|---|---|---|
| | BHN | DHL | FZB | JRH | KAL | PAT | Mean |
| PS/06-88 | 19.51 | 21.70 | 29.50 | 11.61 | 14.00 | 26.65 | 20.50 |
| Kufri Lalima | 16.19 | 14.00 | 26.20 | 11.61 | 25.01 | 22.11 | 19.19 |
| Kufri Lalit | 17.26 | 15.28 | 28.49 | 10.66 | 27.30 | 22.74 | 20.29 |
| CD (0.05) | Location= 0.82; Genotype = 0.93; Location × Genotype= 2.47 | | | | | | |

**Table 6. Total tuber yield (t/ha) of PS/06-88 (2017-18) in Eastern plains at 90 days in on-farm trials**

| Genotypes | 90 days | | | | | | |
|---|---|---|---|---|---|---|---|
| | BHN | DHL | FZB | JRH | KAL | PAT | Mean |
| PS/06-88 | 19.35 | 24.97 | 36.81 | 13.08 | 22.05 | 28.49 | 24.13 |
| Kufri Lalima | 15.46 | 16.3 | 30.82 | 12.12 | 28.38 | 23.73 | 21.14 |
| Kufri Lalit | 17.32 | 18.45 | 34.79 | 10.79 | 31.28 | 24.91 | 22.92 |
| CD (0.05) | Location= 0.83; Genotype = 0.95; Location × Genotype= 2.50 | | | | | | |

ha) and Kufri Lalit (20.29 t/ha) by margin of 7 and 1% at 75 days. The advanced clone PS/06-88 (24.13 t/ha) showd superiority by margin of 14 and 5% over Kufri Lalima (21.14 t/ha) and Kufri Lalit (22.92 t/ha) respectively at 90 days.

***Overall performance of PS/06-88 in AICRP (Potato):*** Based on pooled mean of four years ie 2013-14, 2014-15, 2015-16 and 2017-18, PS/06-88 (19.69 t/ha) yielded 3 and 7% high total tuber yield than control Kufri Lalima (19.18 t/ha) and Kufri Lalit (18.46 t/ha) at 75 days (**Table 7**). However, at 90 days PS/06-88 (22.76 t/ha) yielded 3 and 2% high total tuber yield than control Kufri Lalima (22.10 t/ha) and Kufri Lalit (22.39 t/ha).

## Tuber dry matter

The mean tuber dry matter content of PS/06-88 (**Table 8**) was 18 and 20%, respectively at 75 and 90 days as compared to Kufri Lalima (18 and 19 %) and Kufri Lalit (18 and 19%).

## Keeping quality

At Patna, Kufri Manik showed extremely longer tuber dormancy (> 6 weeks) as no sprouting was observerd till 75 days of storage under ambient conditions. The total weight loss due to rottage and physiological reason was comparatively lower in PS/06-88 (23%) as compared to Kufri Lalima (27%) and Kufri Lalit (28%) after 75 days of on-farm storage (**Table 9**).

**Table 7. Total tuber yield (t/ha) of PS/06-88 over years under AICRP (Potato)**

| Years | Total tuber yield (t/ha) | | |
|---|---|---|---|
| | PS/06-88 | Kufri Lalima | Kufri Lalit |
| | 75 days | | |
| 2013-14 | 20.15 | 18.54 | 16.73 |
| 2014-15 | 19.87 | 19.81 | 20.11 |
| 2015-16 | 18.22 | - | 16.69 |
| 2017-18 | 20.5 | 19.19 | 20.29 |
| Mean | 19.69 | 19.18 | 18.46 |
| % yield increase over control varieteis | | 2.63 | 6.66 |
| | 90 days | | |
| 2013-14 | 20.20 | 21.06 | 19.65 |
| 2014-15 | 22.98 | 24.1 | 24.06 |
| 2015-16 | 23.72 | - | 22.93 |
| 2017-18 | 24.13 | 21.14 | 22.92 |
| Mean | 22.76 | 22.10 | 22.39 |
| % yield increase over control varieteis | | 2.98 | 1.64 |

**Table 8. Mean tuber dry matter content (%) of PS/06-88 in AICRP trials**

| Genotypes | 75 days | | | | | 90 days | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2013-14 | 2014-15 | 2015-16 | 2017-18 | Mean | 2013-14 | 2014-15 | 2015-16 | 2017-18 | Mean |
| PS/06-88 | 18.25 | 17.38 | 18.03 | 19.82 | 18.37 | 19.15 | 18.51 | 19.9 | 21.09 | 19.66 |
| Kufri Lalima | 16.88 | 17.74 | | 19.80 | 18.14 | 18.09 | 18.18 | | 20.66 | 18.98 |
| Kufri Lalit | 19.00 | 17.55 | 18.62 | 18.16 | 18.33 | 18.15 | 17.67 | 18.99 | 19.27 | 18.52 |

**Table 9. Storage behaviour of PS/06-88 at 75 day of storage at Patna (pooled 2016-17 and 2017-18)**

| Genotypes | Dormancy (<or> than 6 weeks) | Sprouting (%) at | | Weight loss (%) | | | |
|---|---|---|---|---|---|---|---|
| | | 6 weeks storage | 75 days of storage | Sprouting | Rottage | Physiological | Total |
| PS/06-88 | > 6 weeks | 0.00 | 0.00 | 0.00 | 10.49 | 12.57 | 23.06 |
| Kufri Lalima | > 6 weeks | 0.00 | 0.00 | 0.00 | 16.08 | 10.95 | 27.03 |
| Kufri Lalit | > 6 weeks | 0.00 | 0.00 | 0.00 | 14.28 | 13.55 | 27.83 |

## Retention of tuber colour

Nearly 50% of potato acreage and production are contributed by Eastern plains region of India. Red-skinned varieties are typically preferred by customers in this area (Dalamu *et al*., 2019). Anthocyanin pigmentation in the tuber periderm and peripheral cortex imparts colour to red potatoes. Tuber appearance is key for fresh potato marketing. Storage conditions affect physical, chemical, and nutritional qualities of potatoes. Smooth skinned red tubers are susceptible to poor retention of skin colours. PS/06-88 has better tuber skin colour retention (Fig. 3) compared to Kufri Lalit and Kufri Lalima after 4 months of cold storage.

## Nutritional values

The average analysis of nutritional components (**Table 10**) revealed the excellence of PS/06-88 for anthocyanin content (68 mg/100 g FW; fresh weight) in tuber flesh as compared to Kufri Lalima (32) and Kufri Lalit (41). The average phenol content was reported to be 71 mg/100g FW in tuber flesh of PS/06-88 compared to 27 in Kufri Lalima and 36 in Kufri Lalit. Potatoes have, in general, relatively low levels of zinc and iron. However, higher consumption quantity and better bioavailability render it as an excellent source of these minerals compared to cereal and legume crops (Burlingame *et al*., 2009). Micronutrient content ie zinc was

**Table 10. Nutritional status of PS/06-88 (mean of 2018 & 2019)**

| Genotypes | Anthocyanin (mg/100 g FW) | Total Phenolics (mg/100g FW) | Zn (ppm)* | Fe (ppm) | Cu (ppm) | Mn (ppm) |
|---|---|---|---|---|---|---|
| PS/06-88 | 68 | 71.00 | 32.54 | 30.19 | 7.95 | 27.48 |
| Kufri Lalima | 32 | 27.16 | 14.17 | 22.97 | 7.11 | 21.20 |
| Kufri Lalit | 41 | 36.23 | 21.00 | 23.97 | 9.26 | 15.75 |

*ppm: parts per million on dry weight basis

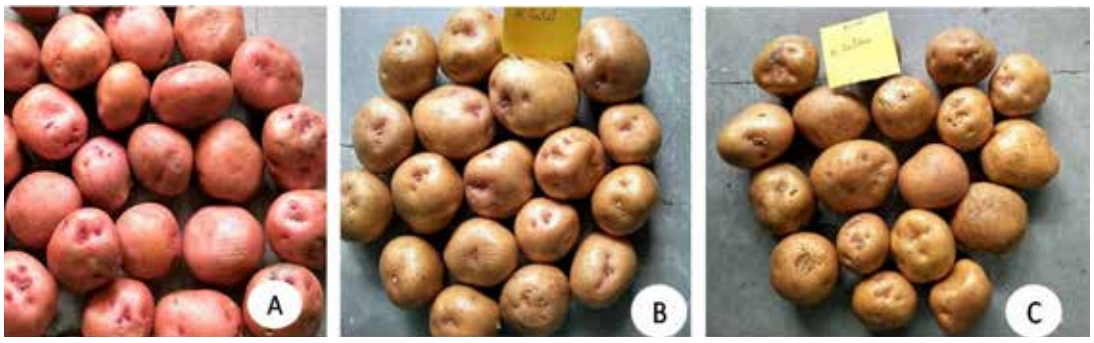



*Fig. 3 Tubers of Kufri Manik (A) and control varieties Kufri Lalit (B) and Kufri Lalima (C) after 4 months of cold storage 4 degree Celsius*

highest in PS/06-88 (33 ppm) in tuber flesh compared to Kufri Lalima (14) and Kufri Lalit (21). Iron content in PS/06-88 (30 ppm) was also more than Kufri Lalima (23 ppm) and Kufri Lalit (24 ppm). Similarly, manganese content was reported highest in PS/06-88 (27 ppm) than Kufri Lalima (21 ppm) and Kufri Lalit (16 ppm). However, Kufri Lalit had highest copper content in tuber flesh (9.26ppm) followed by PS/06-88 (7.95 ppm).

## Usage

The new medium maturing variety Kufri Manik is suitable for table potatoes with attractive deep red round tubers having medium eyes and yellow flesh colour. Tubers of this variety seldom exhibit external/ internal defects and are not susceptible to skin damage at harvest. Its tubers are easy to cook (15-20 minutes) and cooked/boiled tubers are free from any kind of discolouration. The variety possesses a pleasant flavour, waxy texture, and good organoleptic taste. Thus, the desirable tuber characters, good keeping, and culinary quality of this clone will favour its acceptance.

## Disease

PS/06-88 shown moderate resistance to late blight under field conditions at Patna (Bihar). Further, tubers of this clone seldom exhibit external or internal defects and are not susceptible to skin damage at harvest.

## Agronomic management

A regular agronomic programme for medium maturing varieties is required for Kufri Manik. *Planting time*: 25$^{th}$ October to 10$^{th}$ November in Eastern plains. *Seed rate*: 28-30 q/ha. *Seed size*: 40-60 gram *Spacing*: The optimum row to row spacing is 60 cm and plant to plant distance within a row is 20 cm at a planting depth of 10-12 cm. *Fertilizer:* The optimum nitrogen, phosphorus and potassium dose per hectare area for ware potato crop is 150 kg N, 80 kg P2O5 and 100 kg K2O, respectively. Half dose of nitrogen is applied at the time of planting and the remaining 50% N at earthing up. However, nutrient management should be done as per soil test data and regional recommendations. *Weeding and inter-culture*: Pre-emergence herbicide Oxyfluorfen 23.5% EC is to be applied @ 500ml dissolved in 800-1000 litres water per hectare within one week after planting. Earthing-up is done nearly 22-25 days after planting when the crop is 8-12 cm in height. *Irrigation*: Germination, stolon formation and tuber bulking are critical stages for plant moisture requirement. Pre-sowing irrigation is recommended for uniform emergence. Otherwise, first irrigation should be given 4-6 days after planting. Post planting irrigations is recommended at 7-10 days interval in sandy loam soil and 10-12 days in heavy soil. *Plant protection*: For control of leafhoppers and mites, foliar spray of Imidacloprid (200SL) @ 0.03% (3 ml/10 litres of water) or Sulphur 70WP @ 30gm/10 litres of water or Spiromesifen 240SC @ 4ml/10 litres of water at 30-35 days after planting (seed crop only). For the management of other pests like cutworms, white grubs, beetles and leaf eating caterpillars application of Cartap hydrochloride 4G @20 kg/ha during earthing-up. *Late blight*: Although Kufri Manik has field resistance to late blight however, prophylactic spray of Mancozeb or Propineb or Chlorothalonil @ 0.2% (20 gm/10 litres of water) followed by need based application of Cymoxanil + Mancozeb or Dimethomorph + Mancozeb or Fenamidone + Mancozeb @ 0.3% (30 gm/10 litres of water) is recommended.

## Adaptability

Kufri Manik has performed well in multi-location trials conducted under AICRP on Potato and has been recommended for

cultivation in eastern plains (Bihar, Orissa, West Bengal, Assam and Eastern Uttar Pradesh.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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SHORT NOTE

# POTATO MICROPROPAGATION IN A MEDIUM DEVOID OF ANY PLANT GROWTH REGULATORS

**Tanuja Buckseth[1]*, Sumita Sharma[1], Jagesh K Tiwari[2], Ashwani K Sharma[1], MJ Sadawarti[3] and Vinod Kumar[1]**

**ABSTRACT: The MS media without any growth regulator is being used for the potato micropropagation. An analysis demonstrated that microplants developed without the growth regulators proved to have equivalent potential of increasing the multiplication rate of *in vitro* potato varieties. There was no significant difference in the growth and morphological parameters of potato cultivars regenerated with and without the use of growth regulators. The same cost effective protocol has been shared with the seed entrepreneurs and they are successfully following it in their labs.**

**KEYWORDS:** Virus free, *in vitro* plantlets, Plant Growth Regulators (PGRs), MS media

Potato is commonly grown by vegetative propagation through tubers. But for commercial potato production, the availability of quality seeds is a major constraint especially in developing countries like India (Kumar *et al*., 2007). There are severe yield losses resulting in lower productivity of potato crops due to the degeneration of seed stocks over the years. To overcome this problem, conventional methods, rapid multiplication techniques and hi-tech seed production systems like micro-propagation and aeroponics are being used at the commercial level for producing enough quantity of healthy seed tubers in a less time period (Buckseth *et al.,* 2022). Since potato is highly amenable to tissue culture, micropropagation is one of the most commonly used methods for the rapid multiplication of true-to-type genotypes (Tiwari *et al*., 2013). Moreover, tissue culture-based hi-tech seed potato production is a commercially used technology in potato-growing countries including India (Buckseth *et al*., 2016). As per expectations, the clonally propagated plantlets ought to be the exact copy of the mother plant but, a contrasting behavior can be seen when the material involving PGR experiences unfavorable environmental conditions and seasonal cycles. Epigenetic changes are often temporary and plants may revert back to the original phenotype quite effectively, yet some can be long lasting and may even be transferred during sexual propagation (Jullien, 2010). The principle goal of raising potato plantlets is to produce high quality uniform tubers both for seed and table purpose. Any kind of distortion whether genetic or phenotypic, diminishes the market value of potato and raises issues on its usage. Retaining in born strength of in vitro proliferating material is one of the real concerns for analysts (Zilberman and Henikoff, 2007). Unexpectedly, during our routine micropropagation, we observed the tuber shape variation (elongated) in one of the most popular variety Kufri Bahar in the tuber produce of tissue-culture raised plants which were originated from the mother tuber having round shape. These elongated tubers with

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sugary tapering end are highly undesirable and also unsuitable for commercial seed production, and results in rottage and early decay of seed stocks during storage. To achieve healthy and quality seed tubers, the maintenance of the genetic identity of tissue culture-derived plants is very crucial in potato (Tiwari *et al*., 2013). Later, considering the growth regulator as a culprit for tuber shape variation, a decision of exclusive use of hormone –free media for potato tissue culture was taken (Tiwari *et al.,* 2021). Keeping the above factors in view a study was conducted to investigate whether the growth regulators are essential for appropriate development and improvement of potato varieties under controlled conditions.

In the present study (2018-19 & 2019-20), 29 commercial potato varieties were used. MS media with (100 ul/L GA3 and 10ul/L NAA) and without growth regulators supplemented with sucrose (300 g/L) and gelrite (2g/L) was used. The pH was adjusted to 5.8 before autoclaving. The cultures were grown in culture room at 21±2°C temperature under 16/8 h (day/night) photoperiod with 50–60 µmol $m^{-2}$ $s^{-1}$ light intensity. Three explants with single node cuttings (SNC's) were aseptically inoculated in each culture tube (25 × 150 mm) containing MS media. Individual variety was replicated thrice and each replicate consisted of five test tubes and was allowed to regenerate under controlled conditions for 21 days. After twenty-one days of culturing, observations were recorded on morphological parameters such as micro-plant height (cm); number of green leaves, nodes and roots; inter-nodal and root length (cm); fresh as well as dry mass (mg) as described by Naik and Buckseth, 2018.

As the experiment was conducted twice, data were pooled over individual experiments. The analysis of variance was done using the software AGRES and means were separated according to the least significant differences (LSD) at 0.05 level of probability. Significant means were reported as a sum of means and standard errors (±SE). No significant difference was recorded for plant height among the treatments (**Figure 1**, **Table 1**). The maximum plant height was recorded in variety K. Lauvkar in both GR (17.22±0.98) as well as WGR (17.42±0.70) thereby indicating the use of hormone-free media for the *in vitro* mass multiplication. Surprisingly, the minimum plant height was recorded in variety K. Lima in both GR (7.18±0.89) as well as WGR (7.21±1.03) respectively. However, most of the study reported only the significant use of GA3 (1 ppm) and NAA (100ppm) to increase the plant height which indicates the superiority of these chemicals in bringing about enhanced growth.

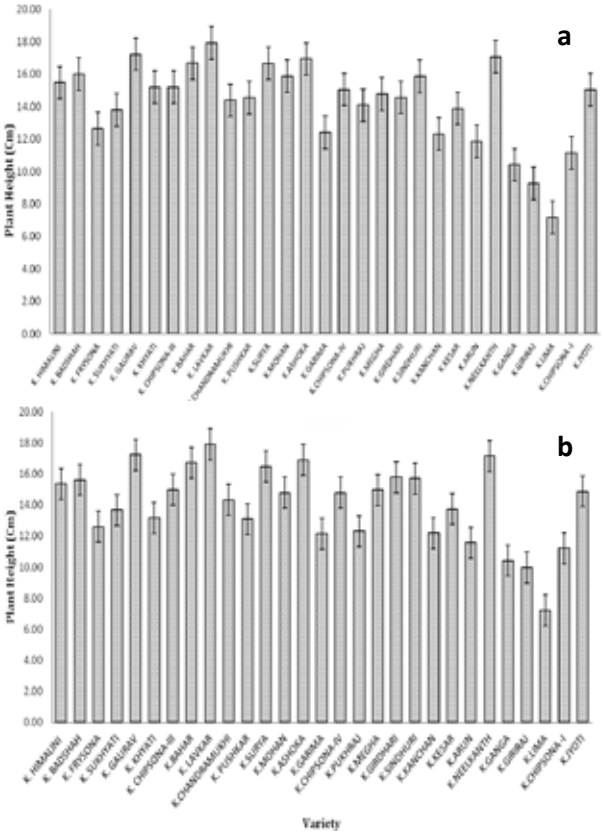



*Figure 1: Microplant height of 29 potato varieties a) GR, b) WGR*

**Table 1: Morphological assessment of *in vitro* propagated potato varieties**

| Varieties | Microplant height (cm) | | Root Length (cm) | | No. of Leaves | | No. of Nodes | | No. of Roots | | Fresh Weight (mg) | | Dry Weight (mg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GR | WGR | GR | WGR | GR | WGR | GR | WGR | GR | WGR | GR | WGR | GR | WGR |
| K. Himalini | 15.47±0.54 | 15.37±0.51 | 6.06±0.40 | 6.03±0.43 | 5.33±0.29 | 5.67±0.35 | 4.89±0.31 | 5.00±0.50 | 15.00±1.83 | 14.89±1.47 | 0.98±0.22 | 1.54±0.44 | 0.07±0.01 | 0.07±0.08 |
| K. Badshah | 16.01±0.51 | 16.01±0.48 | 6.47±0.79 | 6.54±0.95 | 4.33±0.37 | 4.22±0.63 | 4.22±0.55 | 3.78±0.99 | 12.22±4.08 | 12.33±3.70 | 1.27±0.03 | 1.33±0.04 | 0.17±0.07 | 0.10±0.03 |
| K. Frysona | 12.63±1.96 | 12.61±1.44 | 8.18±1.13 | 7.21±1.80 | 4.11±0.72 | 3.89±1.59 | 4.22±1.02 | 3.67±1.66 | 10.00±2.72 | 9.56±2.61 | 1.26±0.19 | 1.24±0.29 | 0.08±0.02 | 0.09±0.09 |
| K. Sukhyati | 13.80±0.79 | 13.69±0.63 | 5.46±0.36 | 5.38±0.71 | 7.67±0.87 | 7.56±1.35 | 6.67±0.78 | 7.11±1.18 | 11.00±2.73 | 10.78±2.62 | 1.43±0.23 | 1.42±0.27 | 0.07±0.03 | 0.06±0.16 |
| K. Gaurav | 17.22±0.98 | 17.24±0.70 | 5.71±0.42 | 5.12±0.79 | 6.33±0.76 | 6.33±1.12 | 6.11±0.89 | 6.22±0.95 | 12.33±2.21 | 12.33±1.81 | 1.45±0.11 | 1.46±0.21 | 0.08±0.01 | 0.08±0.02 |
| K. Khyati | 15.20±1.34 | 13.84±0.66 | 5.61±0.63 | 5.29±0.90 | 5.00±0.55 | 4.78±1.07 | 4.56±0.73 | 4.33±1.22 | 17.11±2.41 | 17.33±1.59 | 1.26±0.05 | 1.24±0.06 | 0.09±0.00 | 0.09±0.03 |
| K. Chipsona-3 | 15.20±1.34 | 15.00±1.42 | 7.52±0.76 | 7.23±1.08 | 5.89±0.75 | 5.67±1.15 | 5.44±0.97 | 5.00±1.63 | 7.11±1.18 | 6.33±1.60 | 1.06±0.09 | 1.07±0.22 | 0.09±0.02 | 0.08±0.13 |
| K.Bahar | 16.67±1.16 | 16.74±0.90 | 8.11±0.66 | 7.36±1.03 | 4.78±0.40 | 4.56±0.55 | 4.89±0.42 | 4.56±0.55 | 7.89±2.06 | 7.67±2.40 | 1.46±0.14 | 1.44±0.24 | 0.09±0.01 | 0.08±0.04 |
| K. Lauvkar | 17.91±0.94 | 17.92±0.78 | 6.26±0.60 | 5.79±0.76 | 6.89±0.82 | 6.89±1.17 | 7.00±0.90 | 6.89±1.17 | 8.22±1.08 | 8.33±1.34 | 1.48±0.12 | 1.51±0.23 | 0.19±0.11 | 0.09±0.03 |
| K.Chandramukhi | 14.39±0.73 | 13.67±0.61 | 7.02±0.73 | 6.80±0.86 | 3.56±0.56 | 3.22±0.49 | 3.56±0.60 | 3.22±0.49 | 8.56±1.88 | 8.78±2.07 | 1.13±0.09 | 1.13±0.17 | 0.08±0.01 | 0.08±0.02 |
| K. Pushkar | 14.54±0.99 | 14.20±1.42 | 7.73±0.69 | 7.20±0.67 | 3.89±0.59 | 3.67±1.06 | 3.78±0.55 | 3.67±1.06 | 8.00±1.89 | 7.67±2.14 | 1.63±0.26 | 1.61±0.26 | 0.08±0.01 | 0.09±0.02 |
| K.Surya | 16.66±1.34 | 16.49±0.96 | 6.12±0.63 | 5.82±1.01 | 4.89±0.61 | 5.44±0.79 | 5.44±0.71 | 5.33±0.83 | 7.44±1.55 | 7.11±1.81 | 1.60±0.26 | 1.52±0.42 | 0.19±0.10 | 0.09±0.10 |
| K.Mohan | 15.87±1.22 | 16.36±1.17 | 5.33±0.71 | 5.40±1.00 | 5.33±0.65 | 5.22±1.05 | 5.22±0.66 | 5.11±1.07 | 13.33±2.96 | 13.22±2.40 | 1.35±0.09 | 1.42±0.13 | 0.15±0.08 | 0.08±0.05 |
| K.Ashoka | 16.93±0.90 | 16.91±0.61 | 6.28±0.57 | 6.22±0.82 | 6.67±0.75 | 6.33±0.73 | 6.67±0.65 | 6.33±0.73 | 10.89±2.30 | 10.78±1.98 | 1.48±0.06 | 1.52±0.08 | 0.15±0.07 | 0.09±0.04 |
| K.Garima | 12.41±1.09 | 12.16±1.14 | 4.73±0.73 | 4.52±1.70 | 4.33±0.53 | 4.11±0.69 | 3.89±0.45 | 4.00±0.71 | 9.44±1.56 | 9.44±1.45 | 1.62±0.20 | 1.63±0.28 | 0.11±0.00 | 0.11±0.05 |
| K.Chipsona-4 | 15.04±0.63 | 14.80±0.41 | 5.80±0.52 | 6.10±0.51 | 5.67±0.33 | 5.56±0.39 | 5.67±0.33 | 5.67±0.35 | 9.67±1.21 | 9.78±1.16 | 1.00±0.07 | 0.95±0.13 | 0.08±0.01 | 0.08±0.04 |
| K.Pukhraj | 14.09±1.65 | 13.98±2.39 | 6.37±0.54 | 5.11±1.33 | 5.67±0.87 | 5.44±1.81 | 5.11±0.79 | 5.22±1.80 | 8.33±2.89 | 8.11±3.20 | 1.19±0.21 | 1.23±0.46 | 0.13±0.04 | 0.09±0.07 |
| K.Megha | 14.77±1.47 | 14.97±1.30 | 6.37±0.69 | 6.32±0.92 | 4.78±0.55 | 4.56±0.75 | 4.44±0.71 | 4.00±0.78 | 11.44±1.68 | 11.33±1.57 | 0.97±0.07 | 1.00±0.20 | 0.08±0.01 | 0.07±0.06 |
| K.Girdhari | 14.56±1.31 | 15.79±1.00 | 4.97±0.55 | 4.59±1.74 | 6.00±0.44 | 5.89±0.52 | 5.89±0.39 | 5.89±0.72 | 8.67±1.47 | 8.56±1.64 | 1.01±0.04 | 0.99±0.10 | 0.07±0.01 | 0.07±0.06 |
| K.Sindhuri | 15.86±0.52 | 16.04±0.50 | 7.06±0.68 | 7.17±0.77 | 6.22±0.57 | 5.89±0.73 | 6.00±0.53 | 5.89±0.73 | 9.22±1.16 | 9.33±1.16 | 0.78±0.08 | 0.79±0.21 | 0.05±0.01 | 0.05±0.10 |
| K.Kanchan | 12.31±0.83 | 12.20±0.95 | 6.16±0.67 | 6.23±0.94 | 4.67±0.29 | 4.56±0.57 | 4.89±0.39 | 4.56±0.57 | 5.33±0.87 | 5.22±1.21 | 0.56±0.07 | 0.54±0.13 | 0.04±0.00 | 0.04±0.00 |
| K.Kesar | 13.89±0.96 | 13.74±1.11 | 5.72±0.26 | 5.83±0.47 | 5.00±0.44 | 4.67±0.76 | 4.44±0.41 | 4.33±0.87 | 8.11±1.71 | 8.22±1.70 | 1.08±0.14 | 1.19±0.28 | 0.10±0.01 | 0.09±0.08 |
| K.Arun | 11.84±0.62 | 11.58±0.57 | 5.63±0.39 | 5.53±0.44 | 4.00±0.33 | 3.67±0.39 | 4.00±0.24 | 3.67±0.39 | 11.56±1.82 | 11.56±1.72 | 1.44±0.09 | 1.50±0.20 | 0.06±0.02 | 0.09±0.05 |
| K.Neelkanth | 17.07±0.86 | 17.16±0.59 | 5.06±0.36 | 4.71±0.51 | 5.89±0.31 | 5.56±0.41 | 5.22±0.32 | 5.56±0.41 | 11.89±2.08 | 11.89±1.92 | 1.05±0.12 | 1.11±0.20 | 0.04±0.02 | 0.06±0.02 |
| K.Ganga | 10.41±0.88 | 10.42±1.00 | 4.54±0.79 | 3.33±0.65 | 4.11±0.45 | 4.00±0.65 | 4.11±0.42 | 4.00±0.65 | 6.67±1.20 | 6.44±1.60 | 0.58±0.04 | 0.62±0.08 | 0.05±0.01 | 0.04±0.00 |
| K.Giriraj | 9.27±0.58 | 9.18±0.49 | 3.96±0.28 | 3.76±0.37 | 2.89±0.35 | 2.56±0.42 | 2.67±0.24 | 2.44±0.42 | 7.44±0.71 | 7.33±0.80 | 0.37±0.09 | 0.38±0.28 | 0.04±0.00 | 0.04±0.03 |
| K.Lima | 7.18±0.89 | 7.21±1.03 | 2.47±0.29 | 2.20±0.73 | 2.44±0.24 | 2.44±0.51 | 2.56±0.24 | 2.56±0.51 | 5.67±1.56 | 5.33±2.08 | 0.35±0.09 | 0.35±0.28 | 0.03±0.01 | 0.04±0.10 |
| K.Chipsona -1 | 11.13±0.41 | 11.37±0.51 | 5.63±0.37 | 5.79±0.46 | 4.67±0.50 | 4.67±1.06 | 4.22±0.46 | 4.89±0.73 | 7.56±0.69 | 7.44±0.76 | 1.31±0.12 | 1.29±0.19 | 0.13±0.01 | 0.13±0.05 |
| K.Jyoti | 15.03±0.14 | 14.88±0.15 | 6.97±0.19 | 7.21±0.22 | 5.78±0.46 | 5.56±0.46 | 5.11±0.48 | 5.33±0.65 | 11.78±1.38 | 11.67±1.23 | 0.80±0.10 | 0.80±0.14 | 0.05±0.01 | 0.06±0.06 |

Significant difference among the treatments were recorded for root length and number of roots (**Table 1**). The maximum root length was observed in variety K. Frysona with GR (8.18±1.13) and in K. Bahar WGR (7.36±1.03). More number of primary and secondary roots were recorded in variety K. Khyati in both WGR (17.31±1.59) and GR (17.11±2.41). In case of number of roots both primary and secondary roots were counted. The maximum roots per plant was observed for K. Khyati in WGR (17.33±1.59) and GR (17.11±2.41) which indicates that the genotype is sole responsible to confer the microplants sensitivity as well as its tolerance limit to different growth hormones (Venkataslam *et al*., 2017).

Easy to root species, (e.g. potato) usually regenerate roots upon subculture on hormone-free medium (Pruski *et al*., 2003). Interestingly, more number of leaves were recorded in variety K. Sukhyati in GR (7.67±0.97) and WGR (7.56±1.35) and, least in variety K. Lima in both the treatments (GR 2.44±0.82; WGR 2.44±0.51) respectively. In the clonal regeneration, sub-culturing cycles influenced morphological characters in the various cultivars differently. In general, 10-12 cycles of sub-culturing is safe to attain or maintain the true-to-type nature of the *in vitro* propagated variety (Buckseth *et al.,* 2017). Genetically controlled in vitro response has already been reported in potato previously (Gopal, 2004). No morphological differences were observed by the additional supplementation of growth regulators in the MS medium by Venkataslam *et al*., 2016. More the number of nodes, more will be the multiplication rate. The results revealed non-significant difference for the node numbers. The highest number of nodes per plant was recorded in K. Sukhyati WGR (7.11±1.18) whereas, GR supplemented media recorded maximum no of nodes per plantlet (7.00±0.90) in K. Lauvkar which otherwise recorded (6.89±1.17) in the absence of GRs. The minimum number of nodes were observed in variety K. Giriraj both in GR (2.67±0.24) and WGR (2.44±0.42). Non-significant differences were observed for fresh weight and dry weight. The data (**Table 1**) indicated that there was no significant change in the weight of all cultivars subjected to the application of GRs compared to the one where no GRs were used. A question frequently placed in connection to the potato shoot polymorphism is the PGR balance required to maintain coherent potato body architecture. This question is subject to extensive research and data analysis. However, one thing is already clear, the green, leafy potato shoot is the main (first, starting, default) shoot type. With such a position, it has the unique

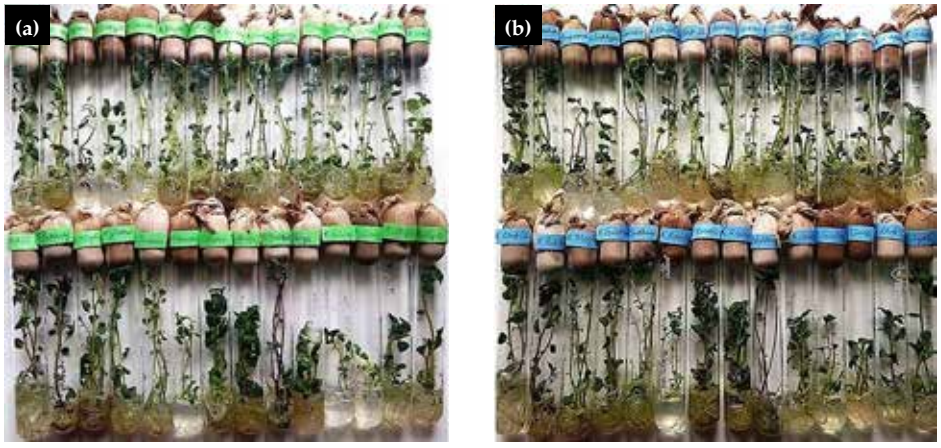



*Figure 2. 29 potato varieties grown in MS media a. With GR'S; b. Without GR'S*

privilege of needing no external PGRs for its growth. Therefore, the leafy potato shoot cultures can complete the whole propagation protocol including the rooting stage on a simple, hormone-free medium. These results are in conformity with Vinterhalter D (2008) (**Figure 2**). The study is simple though informative with lots of practical utility.

The study concluded and signifies that microplants developed without growth regulators proved to have the equivalent potential of increasing the multiplication rate of *in vitro* potato varieties. The same cost-effective protocol has been shared with the seed entrepreneurs and they are successfully following it in their labs.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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# MANUSCRIPT PREPARATION GUIDELINES FOR AUTHORS

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**Thesis**

Kaur RJ (2004) Effect of nitrogen management through organic and inorganic sources in potato. Department of Agronomy, Punjab Agricultural University, Ludhiana, India, Ph.D. thesis: 99p

**Encyclopaedia or dictionary**

Kinni TB (2004) Walt Disney (1901-1966): founder of the Walt Disney company. Encyclopaedia of Leadership. Sage Publications, Thousand Oaks, CA: **1**: 345-49

Cowie AP (1989) Oxford Advanced Learner's Dictionary, 2nd ed. Oxford University Press, Oxford

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| Unit | Abbreviation | Unit | Abbreviation |
|---|---|---|---|
| Centimetre | cm | Milligram | mg |
| Cubic centimetre | $cm^3$ | Millilitre | ml |
| Gram | g | Minute | min |
| Hectare | ha | Nanometre | nm |
| Kilogram | kg | Second | s |
| Litre | l | Square cm | $cm^2$ |
| Metre | m | Square km | $km^2$ |
| Mega gram | Mg | Tonne | t |

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